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PROTOTYPE SCALE MOORING LOAD AND TRANSMISSION TESTS FOR A FLOAT--ETC(U)

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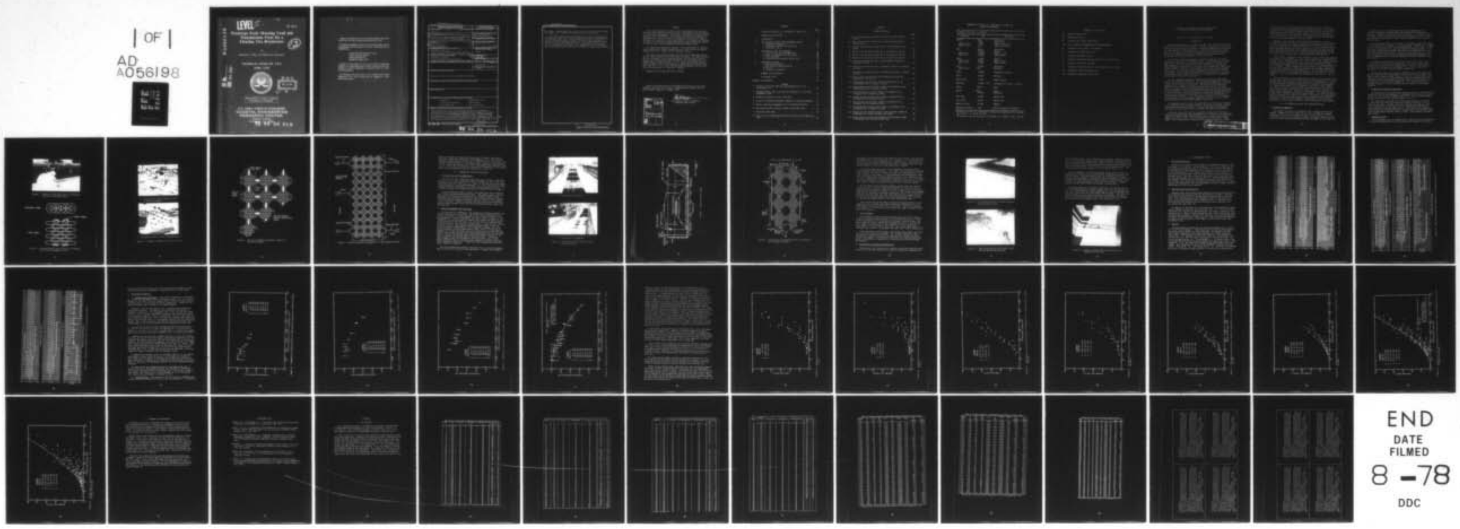

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Prototype Scale Mooring Load and Transmission Tests for a Floating Tire Breakwater

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by

Michael L. Giles and Robert M. Sorensen

TECHNICAL PAPER NO. 78-3

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Prototype scale tests of the mooring load and wave transmission characteristics of a floating tire breakwater were conducted in the large wave tank at the Coastal Engineering Research Center. Standard Goodyear Tire and Rubber Co. 18-tire modules connected to form breakwaters, 4 and 6 modules (8.5 and 12.8 meters, 28 and 42 feet) wide in the direction of wave advance, were tested in water depths of 2 and 4 meters (6.56 and

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13.12 feet). Monochromatic waves with a 2.64- to 8.25-second period range and heights up to 1.4 meters (4.6 feet) were used in the tests.

Test results indicate that wave transmission is mainly a function of the breakwater width to incident wavelength ratio with a slight dependence on the incident wave height. However, the mooring forces are mainly a function of the incident wave height with only a slight dependence on the incident wavelength and breakwater width. Recommended design curves for the wave transmission coefficient versus breakwater width to wavelength ratio and mooring load as a function of incident wave height are presented.

PREFACE

This report describes a brief series of prototype scale tests of a floating tire breakwater system that uses the Goodyear Tire and Rubber Co. tire module arrangement. The report is published to provide coastal engineers with information on the mooring load and wave transmission characteristics of the floating tire breakwater system for a range of incident wave conditions at two water depths. The research was carried out under the structure-sediment-hydraulic interaction research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Michael L. Giles and Robert M. Sorensen, Coastal Structures Branch, Research Division, CERC, under the general supervision of R.P. Savage, Chief, Research Division.

The tests were conducted jointly by CERC and the Lake Erie Marine Science Center (LEMSC) in the CERC large wave tank. The LEMSC provided the tire breakwater and the mooring system. The load cells used to measure the mooring loads were provided by the Lord Corporation, Erie, Pennsylvania, through the LEMSC. Dr. R. Pierce and several students from the LEMSC actively participated in setting up and conducting the wave tank tests. M.L. Giles, the CERC project engineer for the tests, was also assisted by F.L. Lago and L. Meyerle.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director

CONTENTS

FIGURES

CONTENTS

FIGURES-Continued

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

SYMBOLS AND DEFINITIONS

F_n	forward average force
F_p	forward peak force
H_i	incident wave height (centimeters)
H_i/L	wave steepness; incident wave height/wavelength
H_t	transmitted wave height (centimeters)
K_t	transmission coefficient; H_t/H_i
L	incident wavelength (meters)
ℓ	length of breakwater measured parallel to the wave crest
T	incident wave period (seconds)
W	breakwater width measured in the direction of wave travel
W/L	breakwater width/wavelength ratio
Y/D	breakwater depth/water depth ratio

PROTOTYPE SCALE MOORING LOAD AND TRANSMISSION TESTS FOR A FLOATING TIRE BREAKWATER

by

Michael L. Giles and Robert M. Sorensen

I. INTRODUCTION

Floating breakwaters of varying size, shape, and constituent material have been in use for several decades. However, during the past few years there has been an increased interest in floating breakwaters, particularly at sites exposed to short-period waves. They are being used for shoreline erosion control, as combination breakwaters and docks for marinas, and for the temporary protection of dredging and logging operations, waterfront construction, and other coastal activities.

One class of floating breakwaters currently being used at several locations, particularly in sheltered waters, is the floating tire breakwater (FTB). FTB's are constructed of scrap automobile or truck tires made buoyant by plastic foam or some other material and connected to form assemblages of modules with a variety of configurations (Candle and Fischer, 1977). Scrap tires are available at no cost (except transport costs to the site) and are extremely durable when placed in the marine environment. Thus, a floating breakwater made of scrap tires can often be constructed and installed at a low cost in comparison to breakwaters constructed with many other materials.

The most important information needed for an adequate functional design of a floating breakwater is the wave energy transmission characteristics, usually given in terms of the transmission coefficient (ratio of transmitted to incident wave height). The transmission coefficient depends on the incident wave period, height and direction, the water depth, the characteristics of the mooring system, and the characteristics of the breakwater. Floating breakwaters prevent wave energy transmission by reflection and by dissipation primarily through the generation of turbulence in breaking and the interaction of water particle motion with the breakwater structure. Also, the dynamic response of the breakwater to wave motion and the consequent regeneration of waves in the seaward direction helps to diminish wave energy transmission.

An important aspect of the structural design of a floating breakwater is the determination of mooring loads for the range of possible incident wave conditions and water depths. Mooring loads must be evaluated to determine the required mooring line strength and anchor requirements.

There has been little field or laboratory research into the wave transmission and mooring load characteristics of floating tire breakwaters. Kamel and Davidson (1968) conducted model tests, using 15.3-centimeter-diameter (6 inches) tires, for an FTB known as the "Wave-Maze" (Noble, 1969). They evaluated wave transmission and mooring loads for a range

of wave periods (0.75 to 2.5 seconds) and heights 0.03 to 0.30 meter (0.1 to 1.0 foot) at water depths of 0.30 and 0.61 meter (1 and 2 feet). In addition to usual Reynolds number scale effects involved in tests at reduced scale, the mooring load and transmission results obtained in their study may also have suffered scale problems due to the decreased flexibility of the rigid model tires in comparison to the greater flexibility of prototype automobile and truck tires.

Kowalski (1974) reported a brief field investigation of the wave transmission characteristics of a "mat-type" FTB made up of three layers of tires lying flat and strapped together to yield the dimensions 15.2 by 15.2 by 0.46 meters (50 by 50 by 1.5 feet). Two sets of wave measurements were made using a pair of wave gages, one placed seaward and the other shoreward of the FTB. The incident waves had significant heights of 0.8 and 0.9 meter (2.5 and 3.0 feet) and significant periods of 2.0 and 1.8 seconds, respectively. No mooring forces were measured.

Sucato (1975) conducted a brief field test using a module FTB proposed by Goodyear Tire and Rubber Co., with overall dimensions of approximately 25.6 by 5.9 by 0.8 meters (84 by 19.5 by 2.5 feet). Wave transmission and mooring loads were evaluated for an incident wave condition having a significant wave height of 0.46 meter (1.5 feet) and a significant period of 2.2 seconds. Sucato compared the effectiveness of this breakwater to the one used by Kowalski (1974) and found that the Goodyear module-type FTB was more effective in attenuating waves. He also found the mooring loads were less for the Goodyear FTB than for the mat-type FTB. Since loading is cyclic he speculated that premature failure due to creep could occur.

This study measures wave transmission and mooring load characteristics at prototype scale for an FTB constructed of tires arranged in one of the modular forms being used at several locations in coastal waters. Using an 18-tire module arrangement proposed by the Goodyear Tire and Rubber Co. (Candle and Fischer, 1977), breakwaters that were 4 and 6 modules (8.5 and 12.8 meters, 28 and 42 feet) in the direction of wave advance were tested in water 2 and 4 meters (6.56 and 13.12 feet) deep for a range of wave conditions. Tests were conducted in the large wave tank at the Coastal Engineering Research Center (CERC). This report describes the FTB characteristics typical of a field installation, the experimental setup in the large wave tank, experimental procedures, data reduction techniques, and the results obtained. Experimental results and their application to the design of FTB's for field installation are discussed.

II. THE GOODYEAR FLOATING TIRE BREAKWATER SYSTEM

1. Breakwater Components.

The Goodyear floating tire breakwater uses a modular construction concept. Eighteen 14- or 15-inch (36.6 or 38.1 centimeters) standard automobile tires are tied together to form a basic 1.98- by 2.13- by 0.76-meter (6.5 by 7.0 by 2.5 feet) module. Individual modules are then joined to form a floating breakwater of desired length, ℓ, and width, W.

Before the tires are tied together to form a module, two 5.1-centimeter-diameter (2 inches) holes are punched in the bottom and flotation is added to the crown of each tire (Fig. 1). The holes reduce the amount of sand and debris which would accumulate in the tire, and allow water to drain from the tires if the breakwater has to be removed from the water.

When placed vertically in the water, a tire traps a sufficient amount of air in the crown to support its immersed weight. However, this trapped air will dissolve with time or escape through holes in the tire. In addition, each tire provides an ideal environment for aquatic growth. The additional weight of this growth plus the loss of trapped air will eventually cause some tires to sink. The use of flotation materials such as rigid urethane or polystyrene will keep the breakwater uniformly afloat and will permit the use of severely damaged tires which otherwise could not be used.

Individual 18-tire modules are constructed by stacking the tires in a 3-2-3-2-3-2-3 combination and threading a line (e.g., chain, rope) through the tires as they are stacked (Figs. 2 and 3). The weight of the tire stack and physical compression of the tires by hand allow fastening of the line to form a tightly secured unit.

Various types and sizes of chain, synthetic rope, steel cable, and plastic straps are being evaluated in field tests by the University of Rhode Island, Kingston, Rhode Island, for use as a tieline (Davis, 1977). Candle and Fischer (1977) indicate that a specially manufactured 1.27-centimeter (0.5 inch) unwelded, open-link chain is best suited for the construction of floating tire breakwaters. The open-link chain has adequate strength, is easily handled, and can be spliced with simple handtools.

2. Breakwater Assembly and Anchoring.

Interconnection of the individual modular sections to form the desired length and width of the breakwater is accomplished by rotating the four corner tires of each module approximately 100°. Tires are then added to provide interlocking with adjacent modules (Fig. 4).

The breakwater is floated into position and moored (fore and aft) using an open-link chain and steel cable normally placed on a 1 on 7 slope to the anchor. Mooring lines are attached to two modules every 15 to 30 meters (50 to 100 feet) (Fig. 5), depending on the mooring loads expected and type of anchors used. The type of anchor depends on bottom conditions and expected loads. Anchors which have typically been used include formed concrete blocks, pilings, screw anchors, and embedment anchors.

3. Breakwater Costs.

Total breakwater cost will depend on the labor costs for obtaining the tires and assembling the tires into modules, and on types of flotation

Figure 1. Location of flotation material and punched holes in an individual tire.

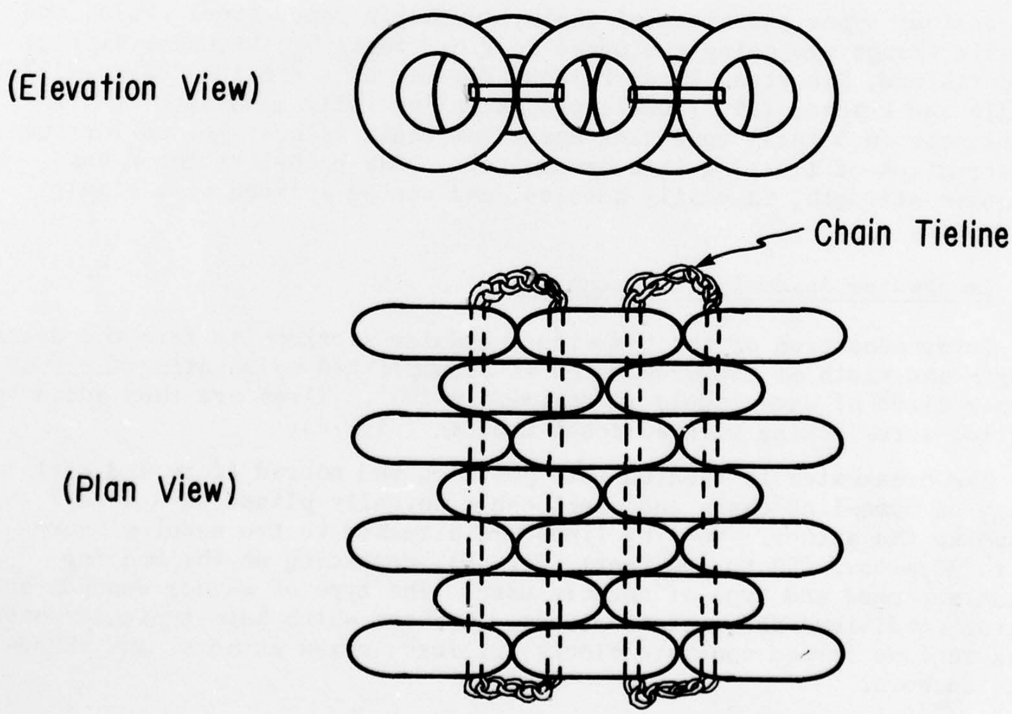
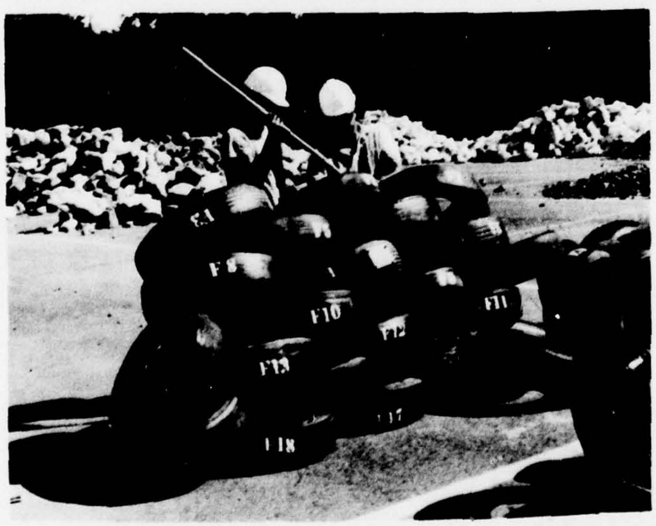


Figure 2. Assembled modular unit consisting of eighteen 14- or 15-inch automobile tires.

a. Threading the chain through the tires as they are stacked.



b. Securing the chain to form a complete module.

Figure 3. Assembly of modules for use in the FTB.

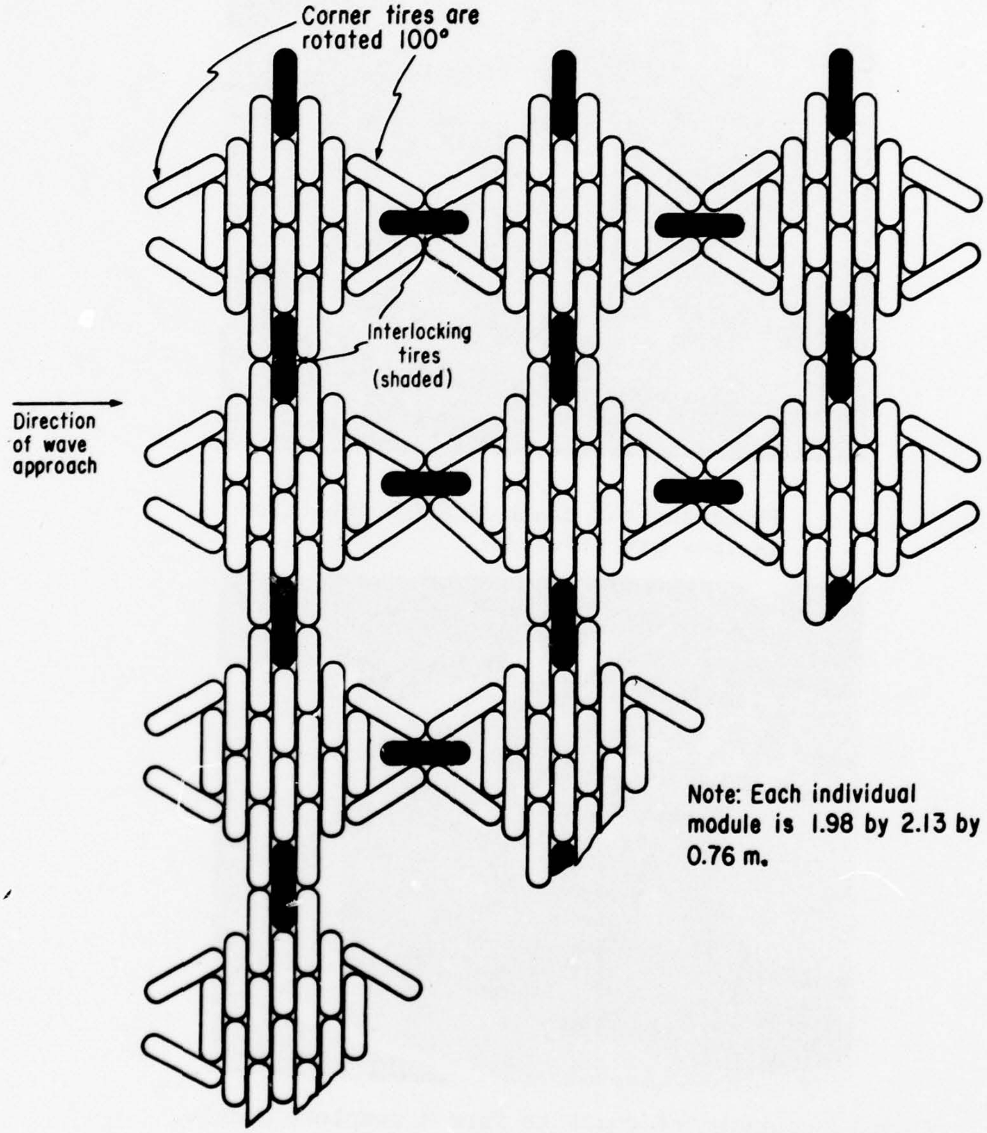


Figure 4. Section of assembled breakwater composed of individual modules.

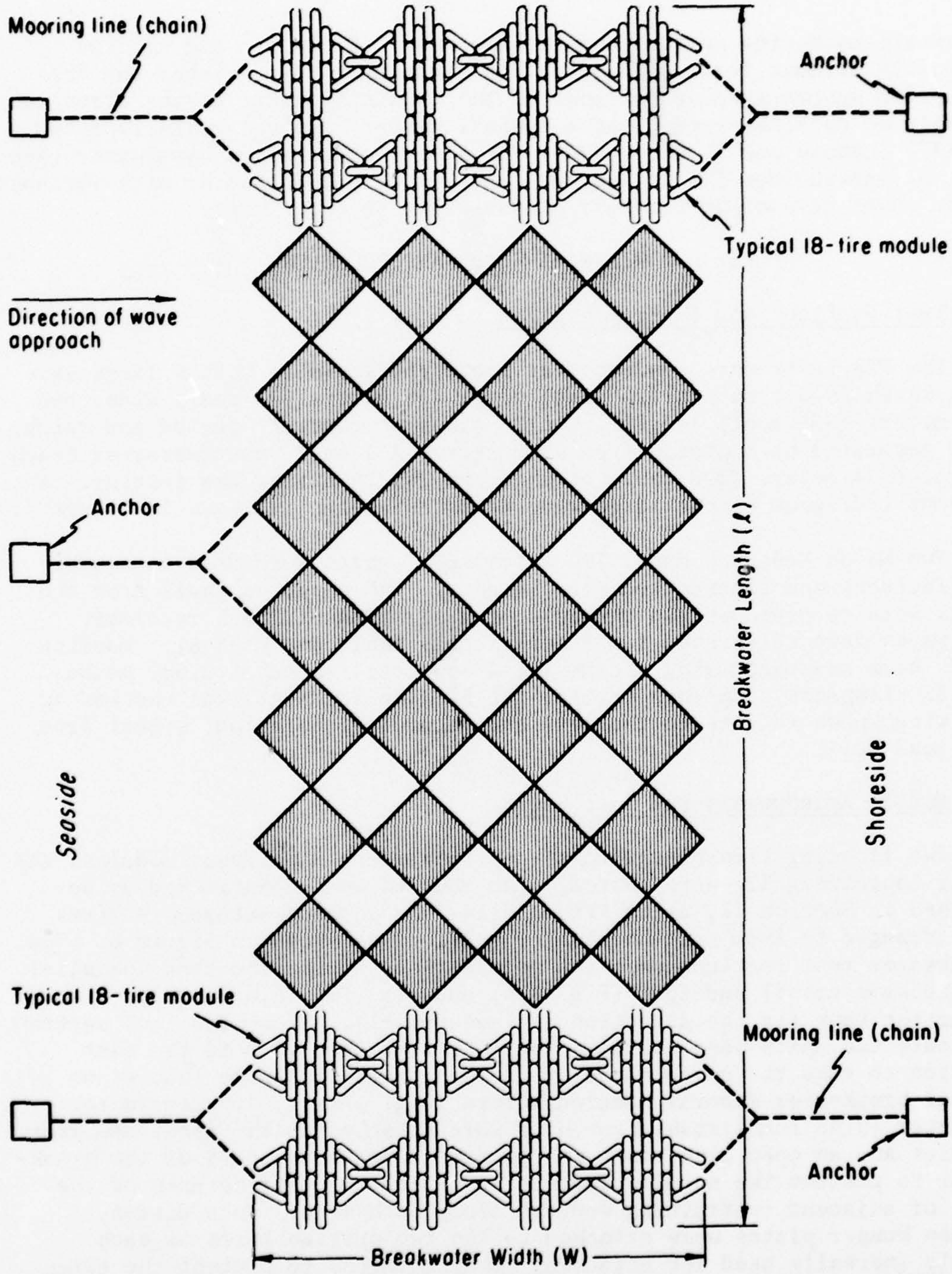


Figure 5. Typical anchoring arrangement for a four-module-wide FTB.

material, anchoring system, and tieline used. Flotation and tieline typically account for one-third of the breakwater cost. Labor and the anchoring system account for most of the remaining costs as the tires can usually be obtained free or at a nominal price. Typical costs reported in 1977 (Candle and Fischer, 1977) for a four-module-wide breakwater (see Fig. 5) varied from $15 to $40 per linear foot of breakwater with variable labor costs accounting for most of variation in total cost.

III. EXPERIMENTAL SETUP AND PROCEDURE

1. Test Facility and Instrumentation.

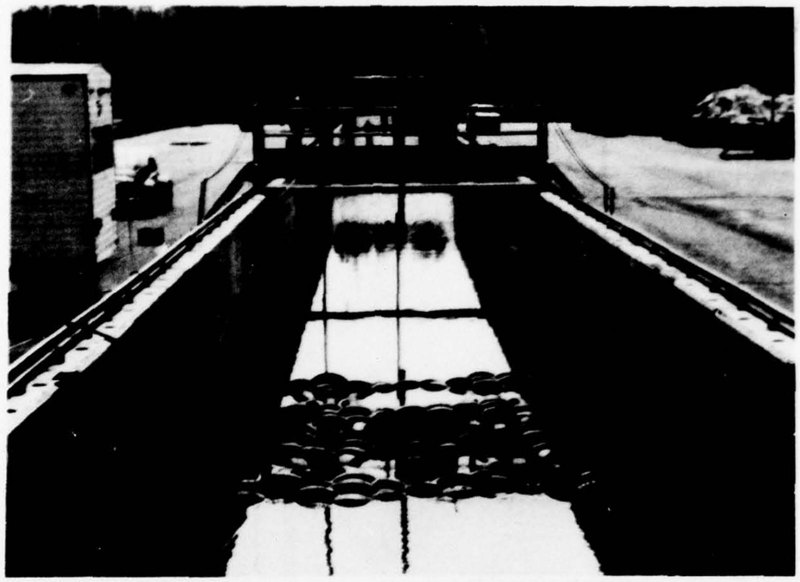
The FTB tests were conducted at prototype scale in CERC's large wave tank which is 6.1 meters (20 feet) deep, 4.6 meters (15 feet) wide, and 194 meters (635 feet) long (Fig. 6). Waves of constant period and height were generated by a piston-type wavemaker. A 1 on 15 sand absorber beach occupied 94 meters (308 feet) of the tank length during the testing. A schematic diagram of the large wave tank test setup is shown in Figure 7.

Two Marsh McBirney model 100 water level gages were used to measure the incident and transmitted wave heights. The output signals from the gages were recorded on two channels of a six-channel Brush recorder. The gages were calibrated for 2 meters full scale per channel. Mooring loads were measured using a commercial load cell rated at 2,500 pounds (1,135 kilograms). Before testing the FTB the load cell was checked by applying known weights to the cell and recording the output signal from the load cell.

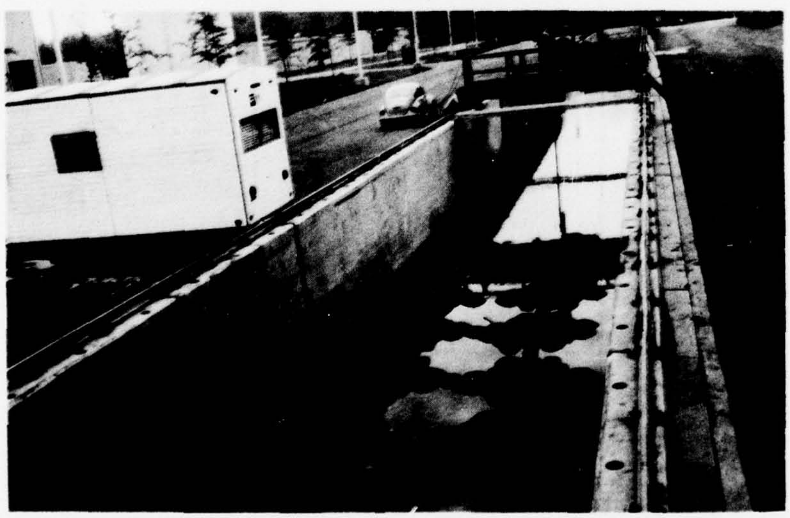
2. Module Arrangement and Test Setup.

Two floating tire breakwaters--one containing 8 Goodyear modules, the other containing 12--were tested. The modules were constructed as described in Section II, using standard 14- and 15-inch automobile tires and arranged to form test breakwater sections as shown in Figure 6. The breakwater test sections were two modules long across the tank (parallel to the wave crest) and four (Fig. 6,a) and six (Fig. 6,b) modules wide along the tank (in the direction of wave travel). Since the test section was only two units long, various modifications were made to the test section to make the performance of the breakwater resemble that of an actual breakwater several hundred meters long. First, 1.9-centimeter-diameter (0.75 inch) stabilizer bars were attached to the front and rear modules and an open-link chain was secured along both sides of the breakwater to prevent the modules from being pulled together because of the lack of adjacent restraining modules along each side. In addition, wooden bumper plates were attached to the two outside tires of each module (normally used for attaching other modules) to prevent the tires from scraping the tank walls. A plan view of the modules and modifications is shown in Figure 8.

The test structure was placed in the tank (Fig. 7), with its seaward edge at station 56.3 (from the wave generator). Incident wave heights



a. Eight-module breakwater.



b. Twelve-module breakwater.

Figure 6. FTB sections before testing in CERC' large wave tank.

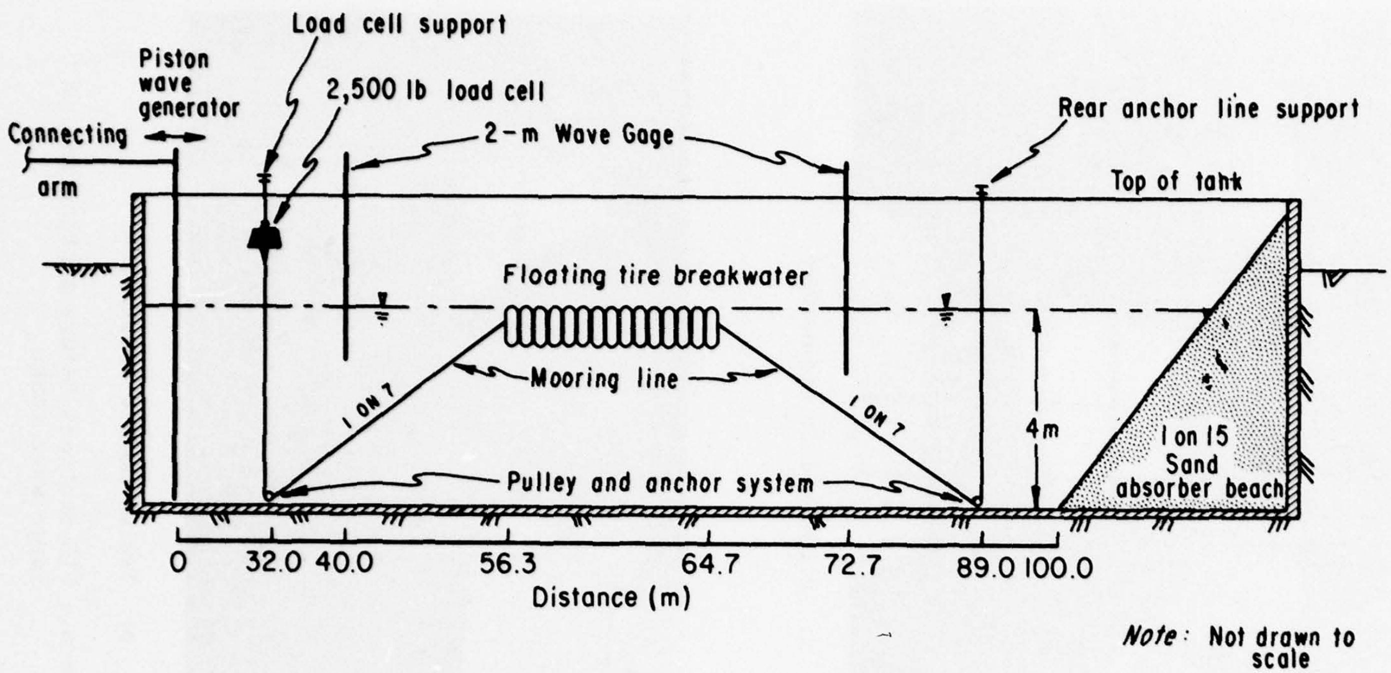


Figure 7. Large wave tank setup.

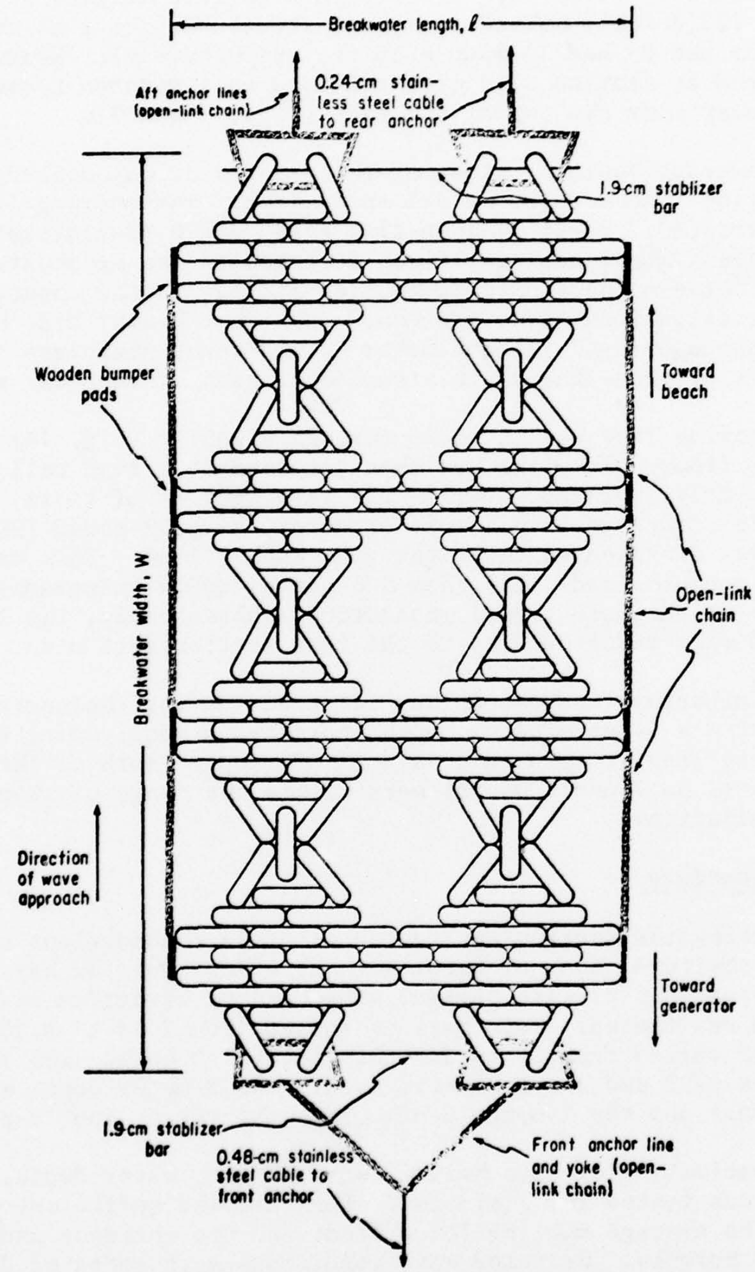


Figure 8. Plan view of an eight-module FTB as installed in the large wave tank.

were measured at station 40.0 and transmitted wave heights were measured 8.3 meters (27.2 feet) behind each test structure (i.e., at stations 72.7 and 77.3 for the 8- and 12-module tests, respectively). Mooring forces were measured at station 32.0 with the load cell mounted above the water surface midway over the top of the tank (Figs. 7 and 9).

The seaward (generator side) of the breakwater was moored using a single mooring line secured on a 1 on 7 slope. The mooring line was made from 6 meters (19.7 feet) of open-link chain and 0.48-centimeter (0.187 inch) stainless steel cable. It was fastened to the breakwater by forming a yoke between the two front modules similar to the connection used in field installations. The shoreward (absorber beach) side of the structure was moored using 0.24-centimeter (0.094 inch) stainless steel cable and 6 meters of open-link chain attached to each of the rear modules.

Each mooring line was threaded through a pulley (Fig. 10) secured to the tank floor. The line was then attached to a load cell (Fig. 9) located directly overhead. During the first series of tests, using the eight-module structure in 4 meters of water, a 2,000-pound (907 kilograms) load cell was attached to the right rear anchor line. This cell did not accurately measure loads less than 100 pounds (45.4 kilograms) because of the lack of adequate signal resolution; subsequently, the load cell was removed when modifications to the test section were made.

Tank limitations and the anchor locations during the series of tests conducted with a 2-meter water depth indicated a requirement that the front mooring line be secured on a 1 on 10 slope. Both of the mooring line slopes (1 on 7 and 1 on 10) were within the range of slopes used in field installations.

3. Test Procedure.

Each breakwater section was tested using wave conditions commonly found on a sheltered body of water such as a reservoir or bay. A total of 165 combinations of wave period, wave height, structure width, and water depth was tested. Wave periods ranged from 2.64 to 8.25 seconds. Wave heights varied from 20 to 140 centimeters (0.66 to 4.59 feet). Water depths of 2 and 4 meters were used: the 2-meter depth with the 12-module unit and the 4-meter depth with both the 8- and 12-module units.

Each combination of wave height, wave period, water depth, and structure width was tested for 5 minutes. This allowed sufficient time to determine the average mooring force loads and the incident and transmitted wave heights. Selected wave conditions were repeated during the study to determine the repeatability of mooring force and wave height measurements.

4. Difficulties Encountered During Tests.

Because each test duration was 5 minutes, reflections from the breakwater and the absorber beach were re-reflected from the breakwater and

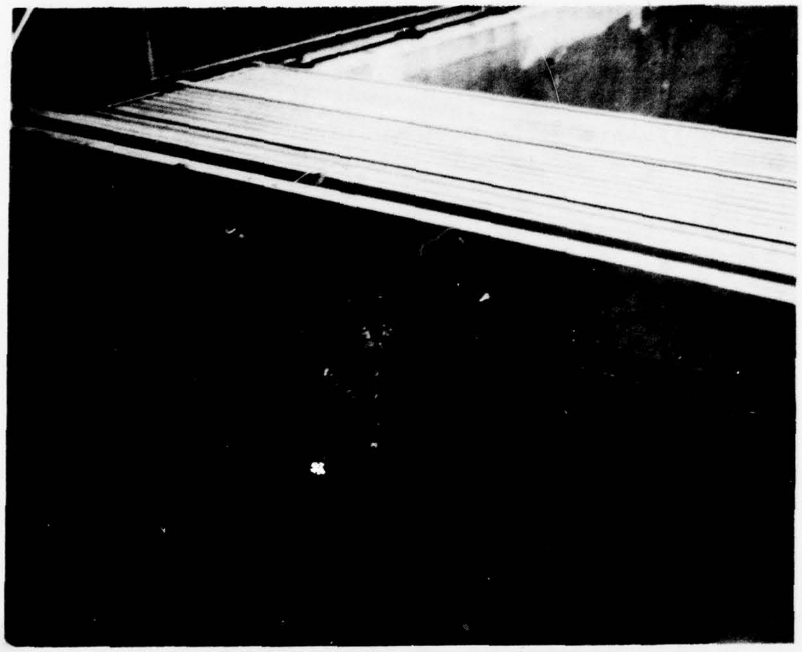


Figure 9. The 2,500-pound load cell used to measure forward mooring forces.

Figure 10. Front anchor-pulley system used to moor FTB and measure mooring loads.

wave generator blade. These reflected waves created a partial standing wave in the wave tank during certain wave conditions. The amplitude of the standing wave was usually small compared to the incident wave height but did require special considerations when determining the incident and transmitted wave heights and the peak and average mooring loads. Wave and mooring force record analysis is discussed in Section IV.

Several attempts to moor the breakwater failed due to either the mooring line breaking, or the anchor-pulley system pulling loose from the tank floor. The front mooring line was a flexible cable with a rated breaking strength of 3,700 pounds (1,678 kilograms). Despite this strength the cable broke three times during the testing period. The failure was caused by fatigue of the line at the pulley. A larger diameter pulley should solve this problem in future tests.

The front anchor was originally installed in the tank by jacking 5.08-centimeter-diameter (2 inches) pipes across the tank bottom (Fig. 11). This system was soon found inadequate as it was pulled away from the floor with a force of 1,200 pounds (544 kilograms). (Maximum loads measured during the test period exceeded 2,000 pounds.) The anchor-pulley system was then bolted to the floor and was able to withstand the larger forces encountered later in the study (Fig. 10).

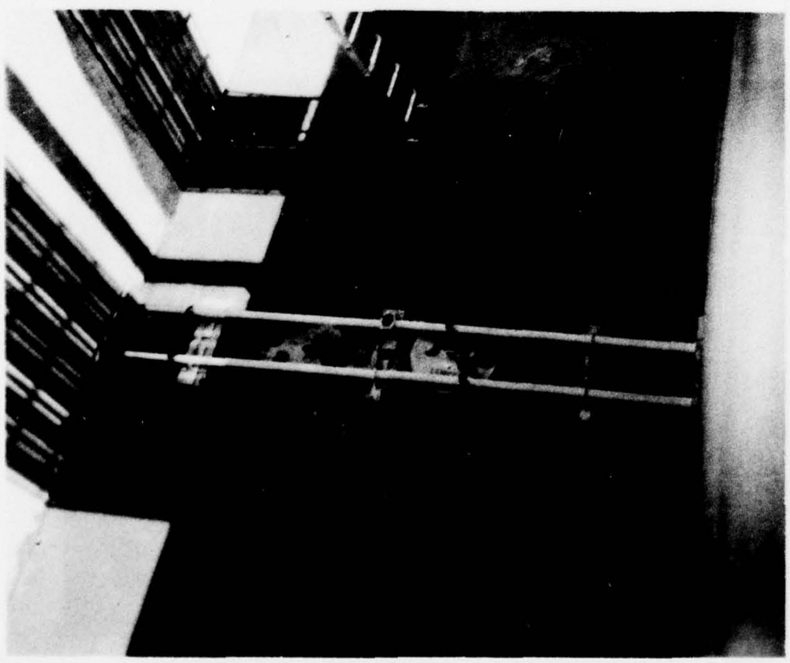


Figure 11. Original anchor-pulley system used at the beginning of the study.

IV. EXPERIMENTAL RESULTS

1. Wave Record Analysis.

Typical wave records for the incident and transmitted waves are shown in Figures 12, 13, and 14. For the majority of the tests conducted, the wave height was uniform for the first 10 waves or so before the effects of reflected waves were observed. This allowed an accurate determination of the average value of the incident and transmitted wave heights to be made before reflected waves from the beach and wave generator modified recorded values. The wave records for the steeper wave conditions (Fig. 12) were more complex due to nonlinear effects. Incident and transmitted wave heights for these records represent an average of the highest one-third of the waves before the reflected waves reached the gage. All wave records were analyzed by hand and independently checked to ensure accurate determination of the values reported.

2. Mooring Force Record Analysis.

Maximum (peak) and average forward mooring forces associated with each test condition were measured from the mooring force records. The peak anchor force was taken as the maximum load recorded during the 5-minute test. This value occurred at the beginning of most of the records as shown in the forward load record in Figures 12 and 13. However, for a few conditions the peakload did not occur until after reflected waves had reached the gage (Fig. 14).

In addition to the peak force an average force was obtained by averaging the highest one-third of the cyclic peakloads. This value represents conditions that include the reflected waves. As shown in Figure 12, the average force is fairly constant during the part of the record when reflected waves were occurring. However, for some wave tests, the average force increased and decreased with time (Fig. 14). This varying force appeared to depend on the test period, water depth, reflected wave height, and breakwater width.

3. Results.

Wave measurements and mooring line force measurements for all tests are listed in the Appendix. Since several test conditions were repeated to assure quality control over the experiment, the composite incident wave height, transmitted wave height, and peak and average loads are also listed in the Appendix for each test condition. The transmission coefficient, K_t, was obtained by dividing the transmitted height, H_t, by the incident height, H_i. The wavelength, L (in meters), was calculated from the wave period and water depth using linear wave theory. Wave steepness, H_i/L, was found by dividing the incident height by the wavelength. W/L represents the ratio of the breakwater width to the wavelength. Peak force, F_p, and average force, F_n, are shown in kilograms per meter of breakwater length parallel to the wave crest (uncorrected

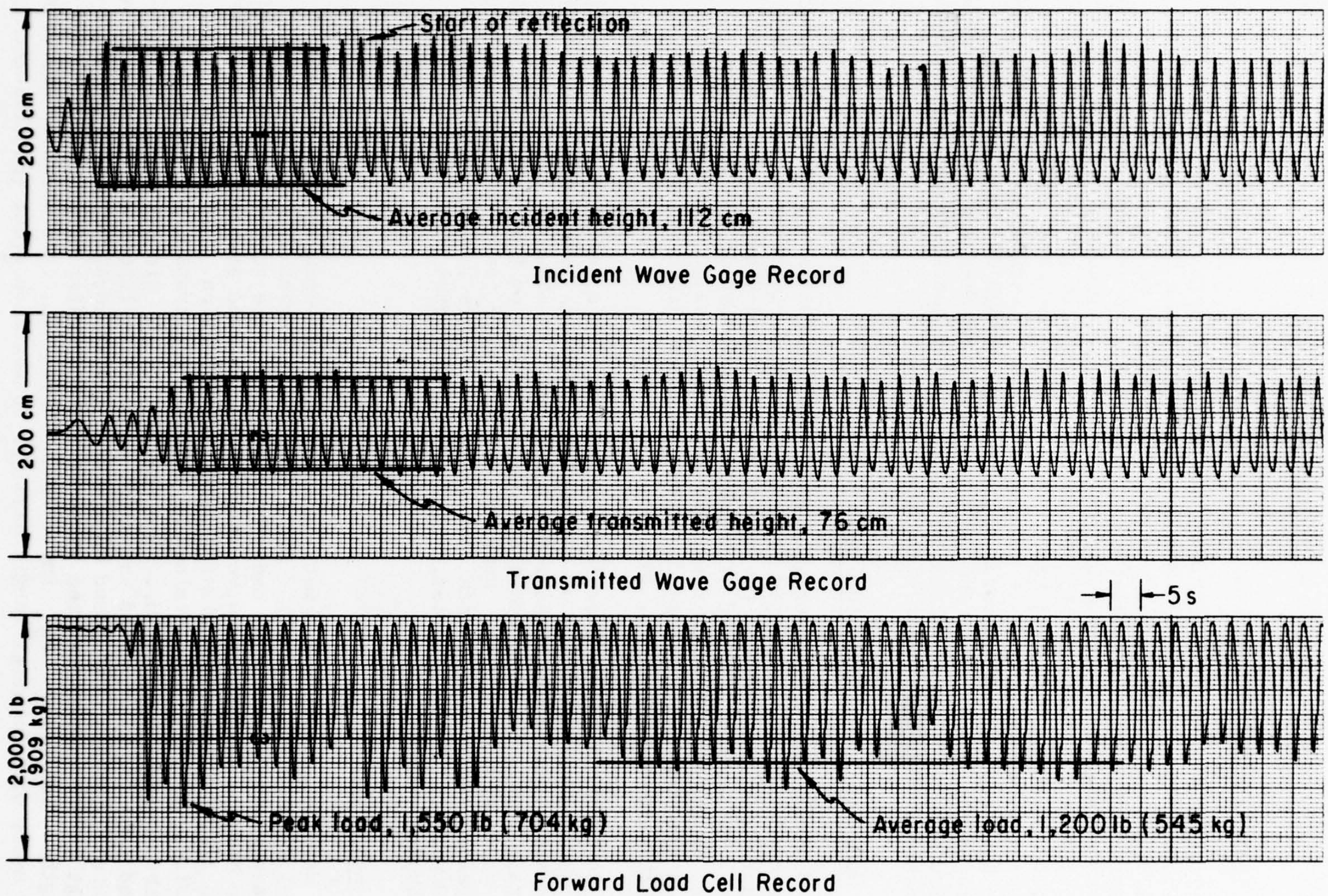


Figure 12. Typical wave and force records for a 3-second wave period.

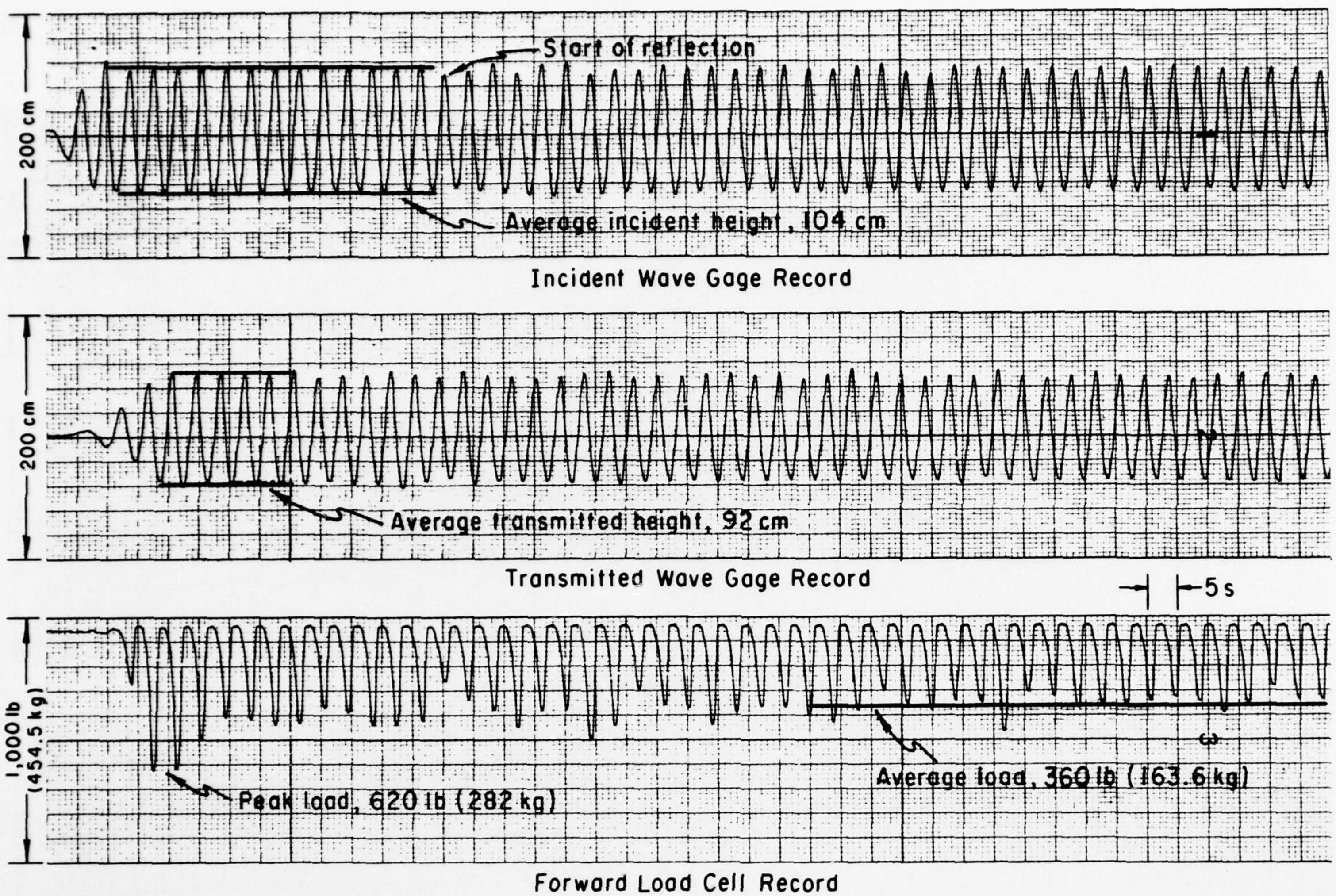


Figure 13. Typical wave and force records for a 4-second wave period.

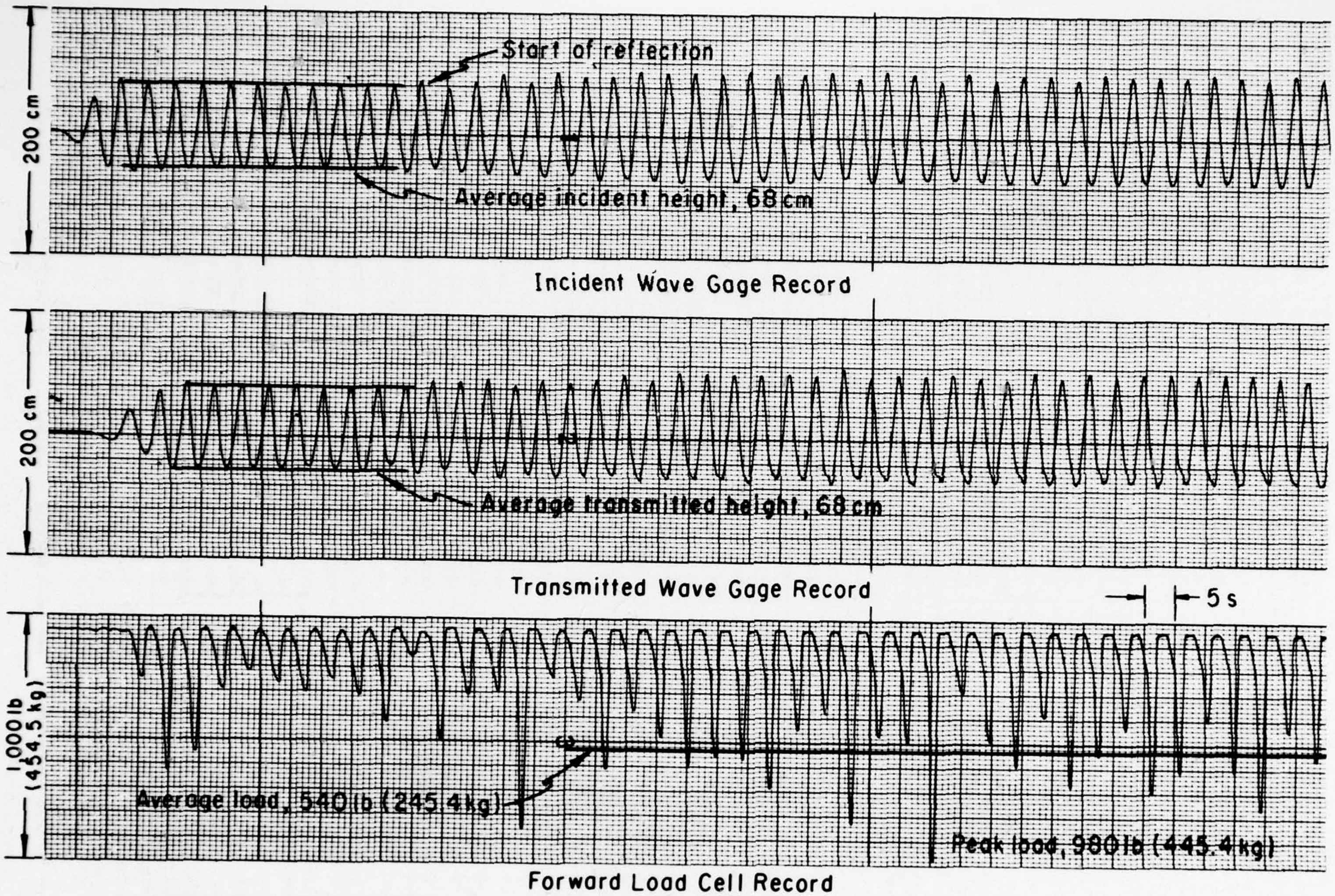


Figure 14. Typical wave and force record for an 8-second wave period.

for the slope of the mooring line since the difference between the horizontal and slope force components is negligible for the slopes used).

4. Discussion of Results.

a. Transmission Coefficient. Plots of the transmission coefficient, K_t, versus the breakwater width to wavelength ratio, W/L, are shown in Figures 15, 16, and 17 for the 8-module FTB in 4 meters of water and the 12-module FTB in 4 and 2 meters of water, respectively. Ranges of incident wave heights are indicated by the legend symbols.

Generally, the data show that as W/L increases the transmission coefficient decreases. As expected, the transmission coefficient is asymptotic to unity as W/L approaches zero. Also, for the same value of W/L, as the incident wave height increases, the transmission coefficient decreases slightly. There is considerable scatter in the data for W/L values less than 0.40. This is because the incident wave height was usually small and was only 2 to 4 centimeters greater than the transmitted height. Thus, a small change in the measured transmitted height causes a large change in the value calculated for the transmission coefficient.

For each of the test sections, minimum measured values obtained for K_t were 0.7 for a W/L of 0.7 for the 8-module FTB in a 4-meter water depth, 0.5 for a W/L of 1.1 with a 12-module FTB in a 4-meter water depth, and 0.3 for a W/L of 1.35 with a 12-module FTB in a 2-meter water depth.

Comparing the data from the 8-module FTB (Fig. 15) and the 12-module FTB (Fig. 16) for the same water depth, transmission coefficients for the 12-module FTB appear to scatter less than the 8-module FTB for given wave heights. Also, the 8-module FTB appears to be more efficient in reducing wave transmission than the 12-module FTB for the same W/L ratios. However, closer examination shows that for the same W/L ratios, the incident wave heights were larger for the 8-module FTB data than with the 12-module FTB. Thus, as previously noted, for the conditions tested the larger the height, the better the FTB attenuates waves.

A comparison of Figures 16 and 17 (12-module FTB's in 4- and 2-meter water depths, respectively) shows that for the conditions tested the water depth does not appear to influence the transmission coefficient. This observation is contrary to the expectation that as more of the water depth is taken up by the breakwater section, the wave attenuation should increase.

By plotting all the transmission data on one figure (Fig. 18), a design curve can be drawn which predicts the transmission coefficient for a given breakwater width to wavelength ratio. The curve is based on data having W/L ratios up to 1.4, wave heights up to 140 centimeters (4.6 feet), and water depths of 4 meters or less.

a. Mooring Forces. Two measures of the mooring force (peakload and average load) were obtained for each of the test conditions. The peakload

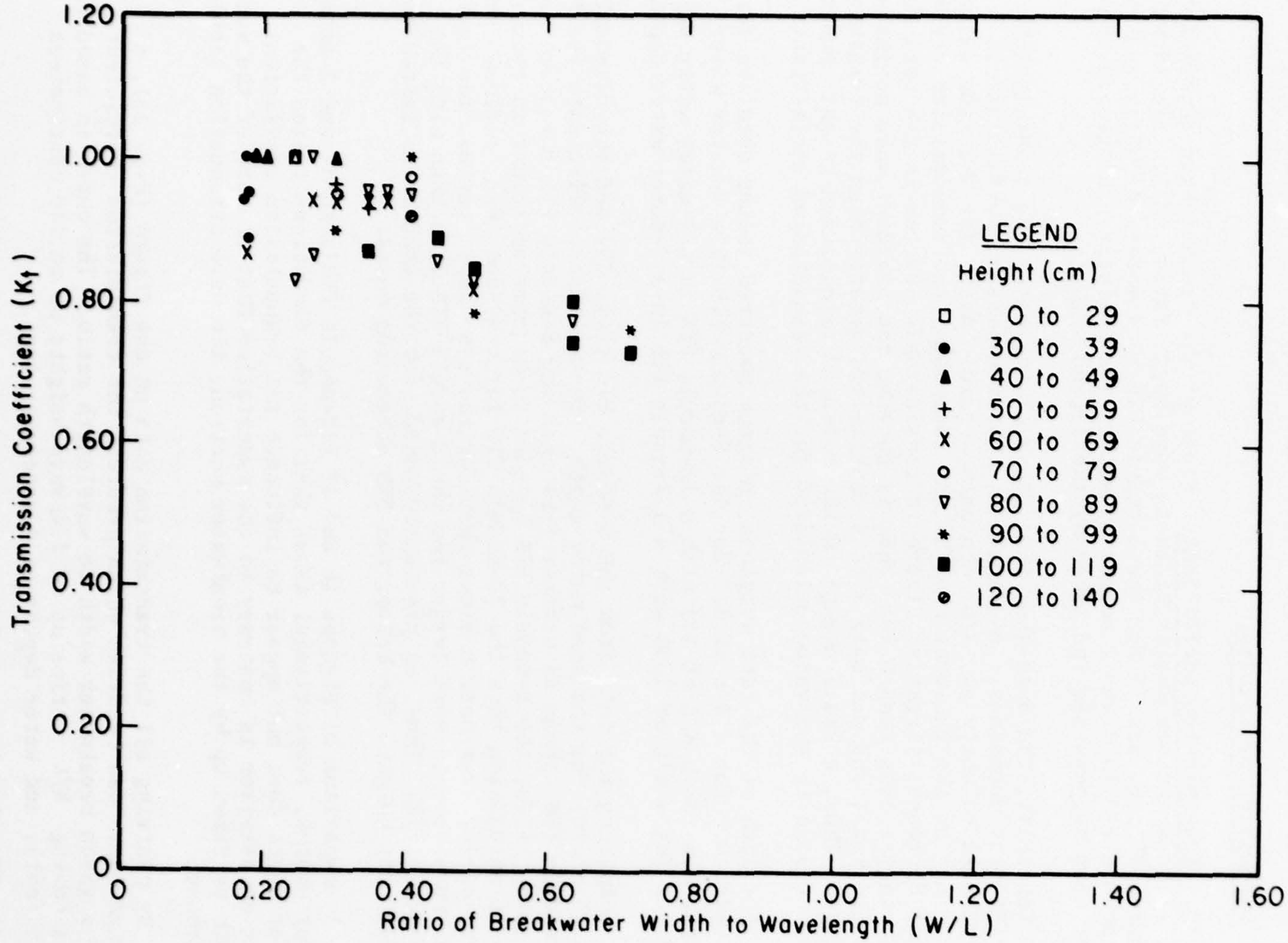


Figure 15. Transmission coefficient for an eight-module structure in 4 meters of water.

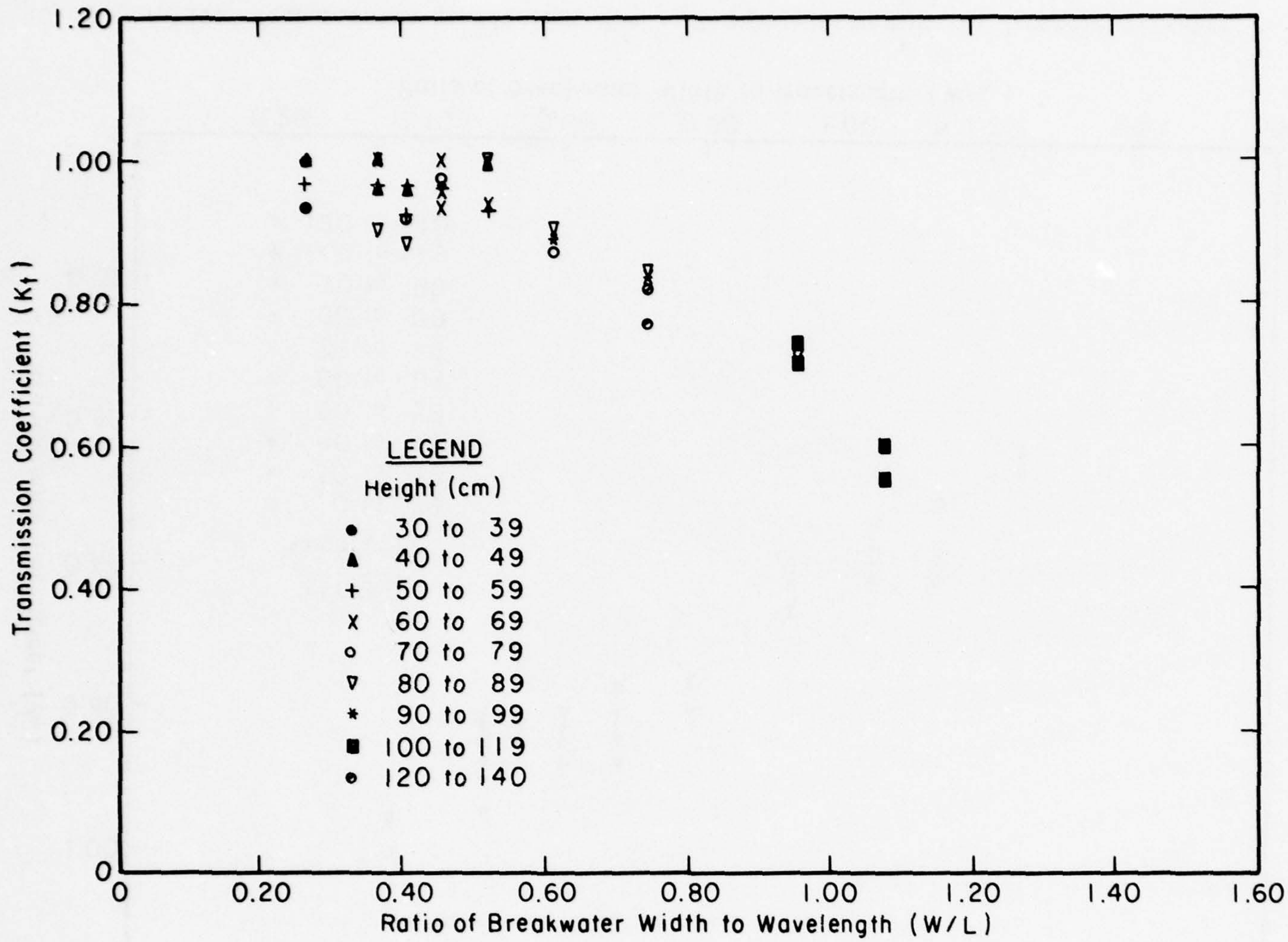


Figure 16. Transmission coefficient for a 12-module structure in 4 meters of water.

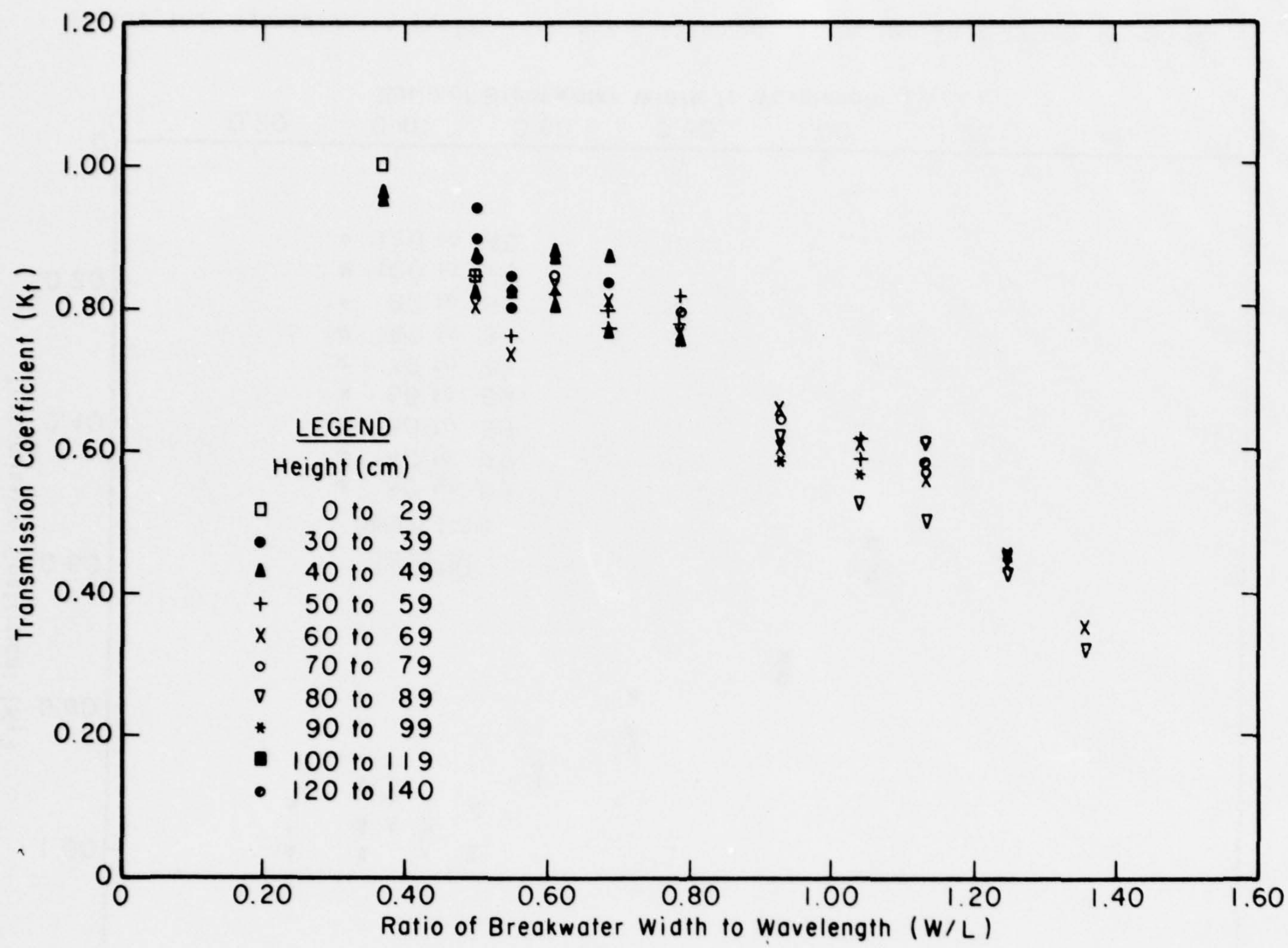


Figure 17. Transmission coefficient for a 12-module structure in 2 meters of water.

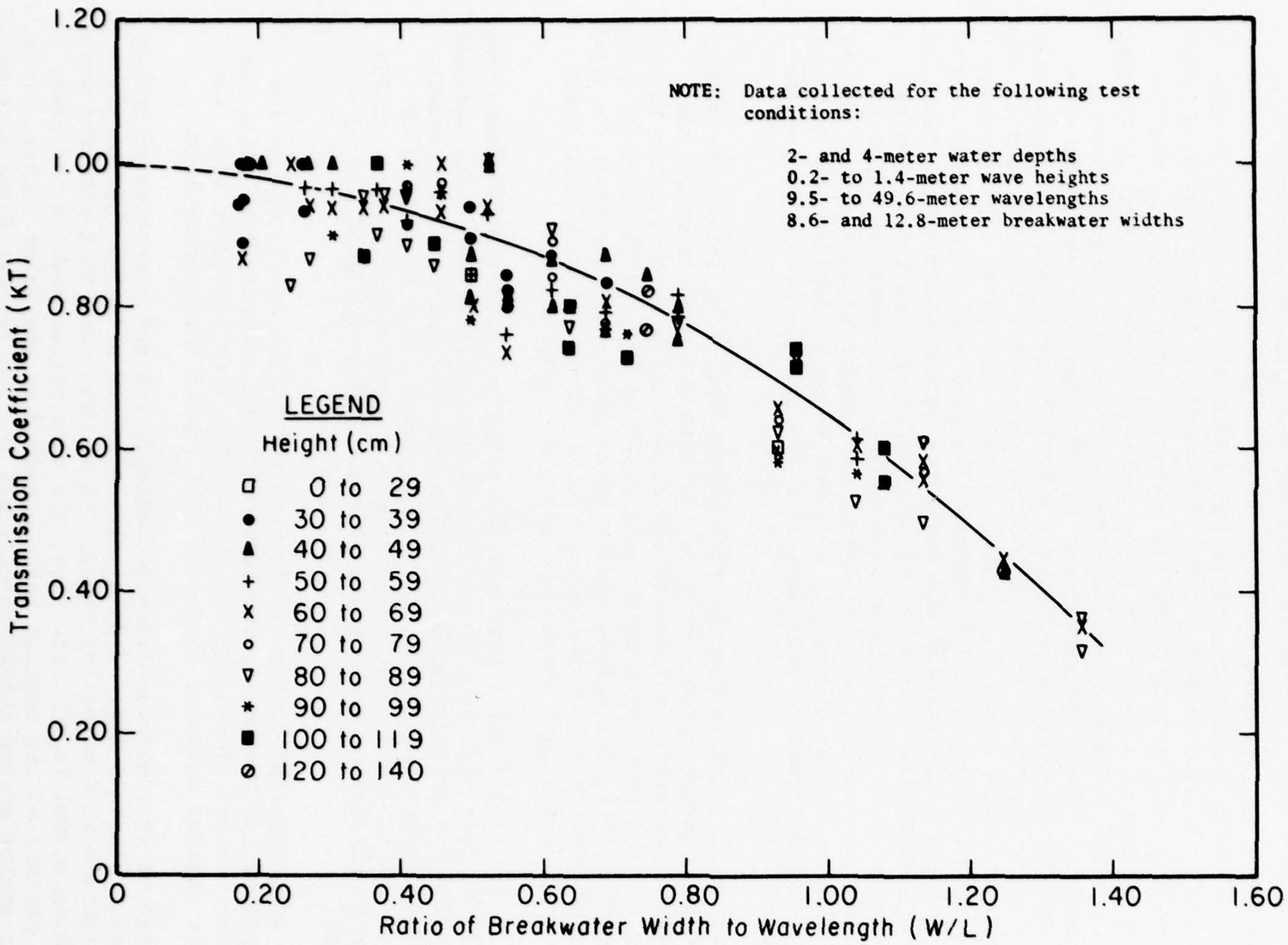


Figure 18. Design curve for predicting the transmission coefficient knowing the W/L ratio.

and the average load per meter length of the breakwater for given incident heights for the 8-module FTB in 4 meters of water and the 12-module FTB in 4 and 2 meters of water are shown in Figures 19 to 24, respectively. In comparing the peak force to the average force for each of the three conditions, it is noted that the peak force is the same or only slightly higher for the 8 modules in 4 meters of water and the 12 modules in 2 meters of water. However, when comparing the 12-module structure in 4 meters of water the peak force is about 20 percent higher than the average force; the peak force is the largest overall force recorded. This indicates that for the same wavelength and wave height, additional modules increase the peak force slightly. Since only two breakwater lengths were tested, it is impossible to determine if this trend will continue if the breakwater width is increased significantly over the tested length of 12.8 meters. The peak forces presented in the various figures represent the maximum force measured during the test, as discussed previously. These forces usually occur when the motionless breakwater is first subjected to wave motion. The relative velocity between the water motion and breakwater is largest at this time. As the mass of the breakwater increases, a larger force is required to initiate movement of the structure and there is a longer time period before the force levels off.

In all cases, the larger the wave height and W/L ratio, the higher the peak and average force. However, no strong steepness or period effect was discernible in the data for either the peak or average force. Plotting all the peak force data together (Fig. 25) and the average force data together (Fig. 26) allows conservative prediction curves to be drawn through the upper parts of the data. These curves approach zero force when the incident height approaches zero, as expected.

Since the peak force represents the situation when the breakwater was initially at rest and then subjected to monochromatic waves, the maximum force that would be calculated using the peakload curve would probably be somewhat larger than the peakload that would occur in a train of irregular waves. Therefore, a conservative force prediction for an FTB would be to obtain the mooring force load based on the peakload curve (Fig. 25).

The anchor design depends as much on the bottom conditions as the force applied and the anchor should be designed accordingly. Also, the connection between the anchor and the mooring line should be such that it allows maximum movement to prevent fatigue of the mooring line.

Design of rear mooring lines and anchors was not investigated during the study. However, limited data were collected with the four-module-wide structure in 4 meters of water. These data show that with the waves approaching normal to the structure, the rear forces were on the order of 5 to 10 percent of the maximum force obtained on the front anchor. Thus, the rear anchor system should be designed for the largest force determined by either the force of the largest wave coming from the shore or, e.g., 20 percent of the seaward force.

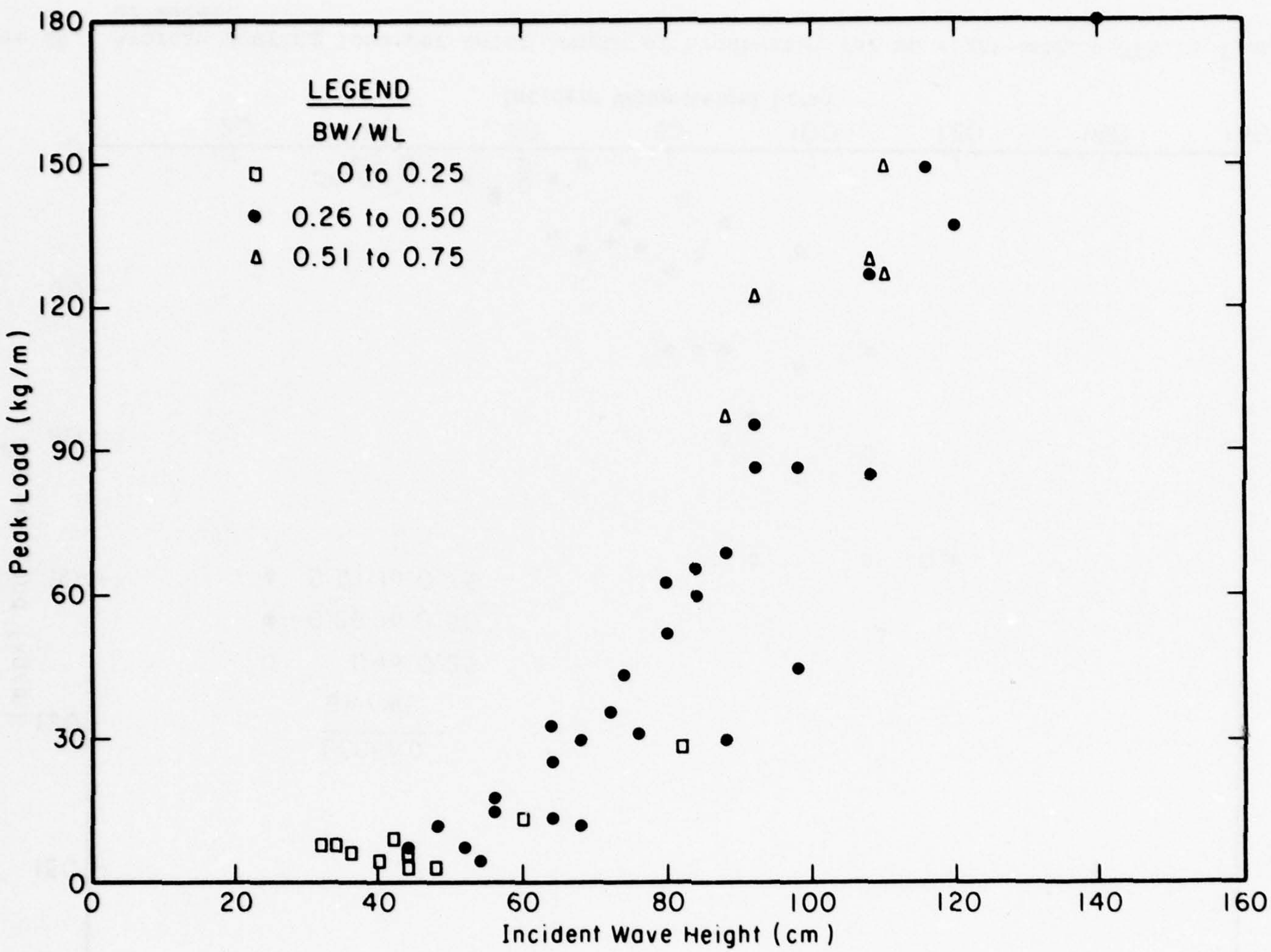


Figure 19. Peak mooring load per meter length of breakwater for an eight-module FTB in 4 meters of water.

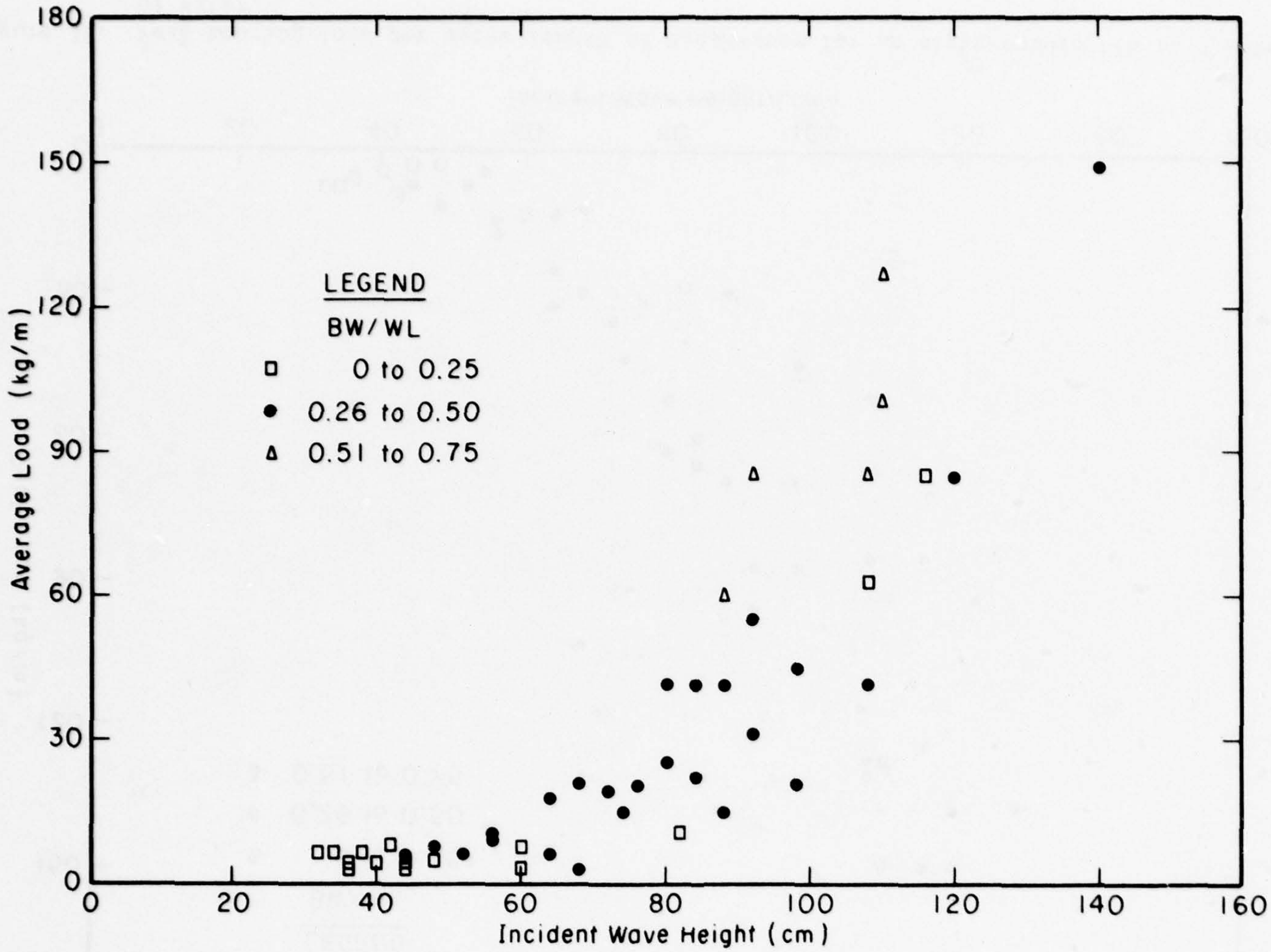


Figure 20. Average mooring load per meter length of breakwater for an eight-module FTB in 4 meters of water.

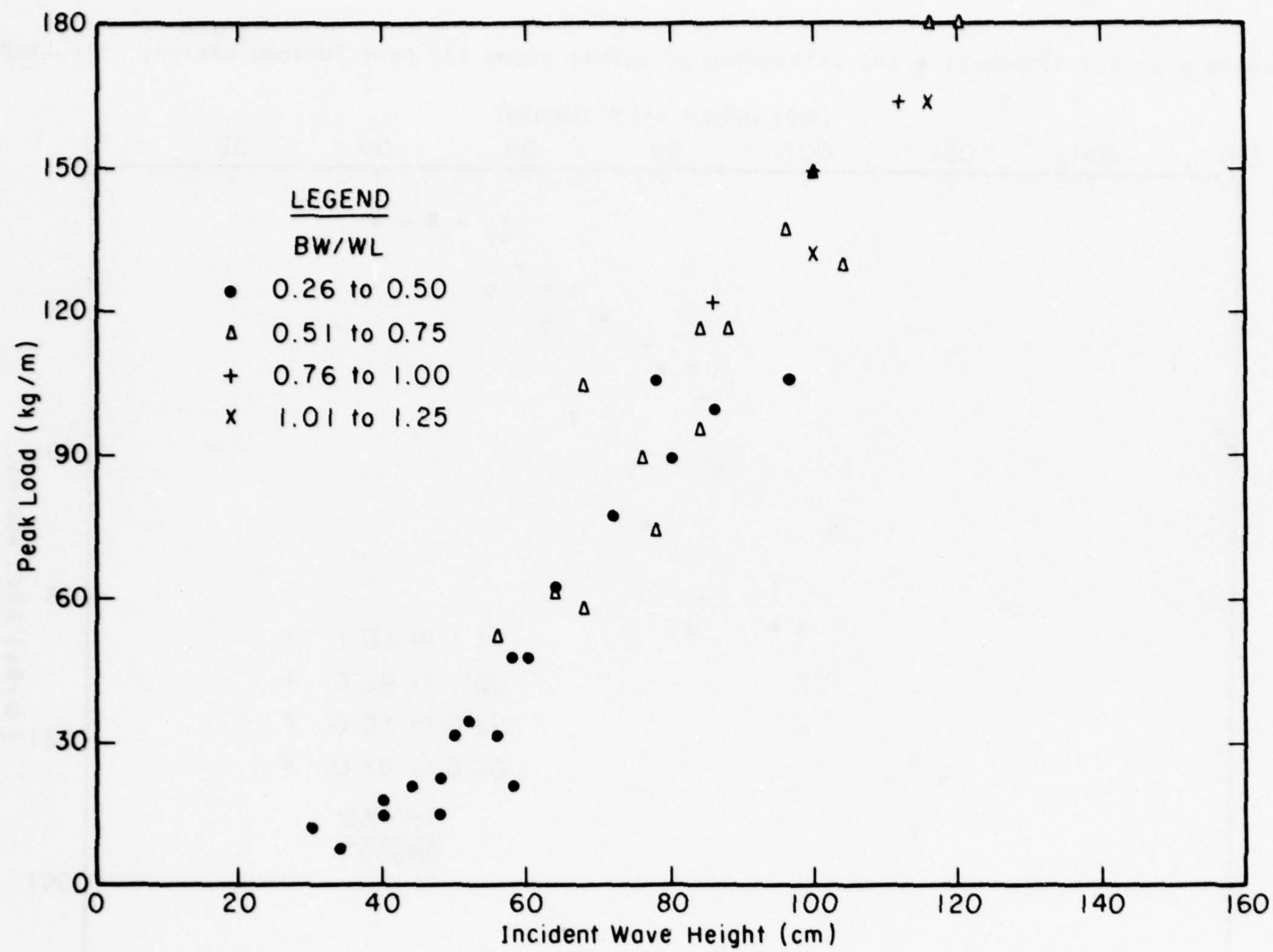


Figure 21. Peak mooring load per meter length of breakwater for a 12-module FTB in 4 meters of water.

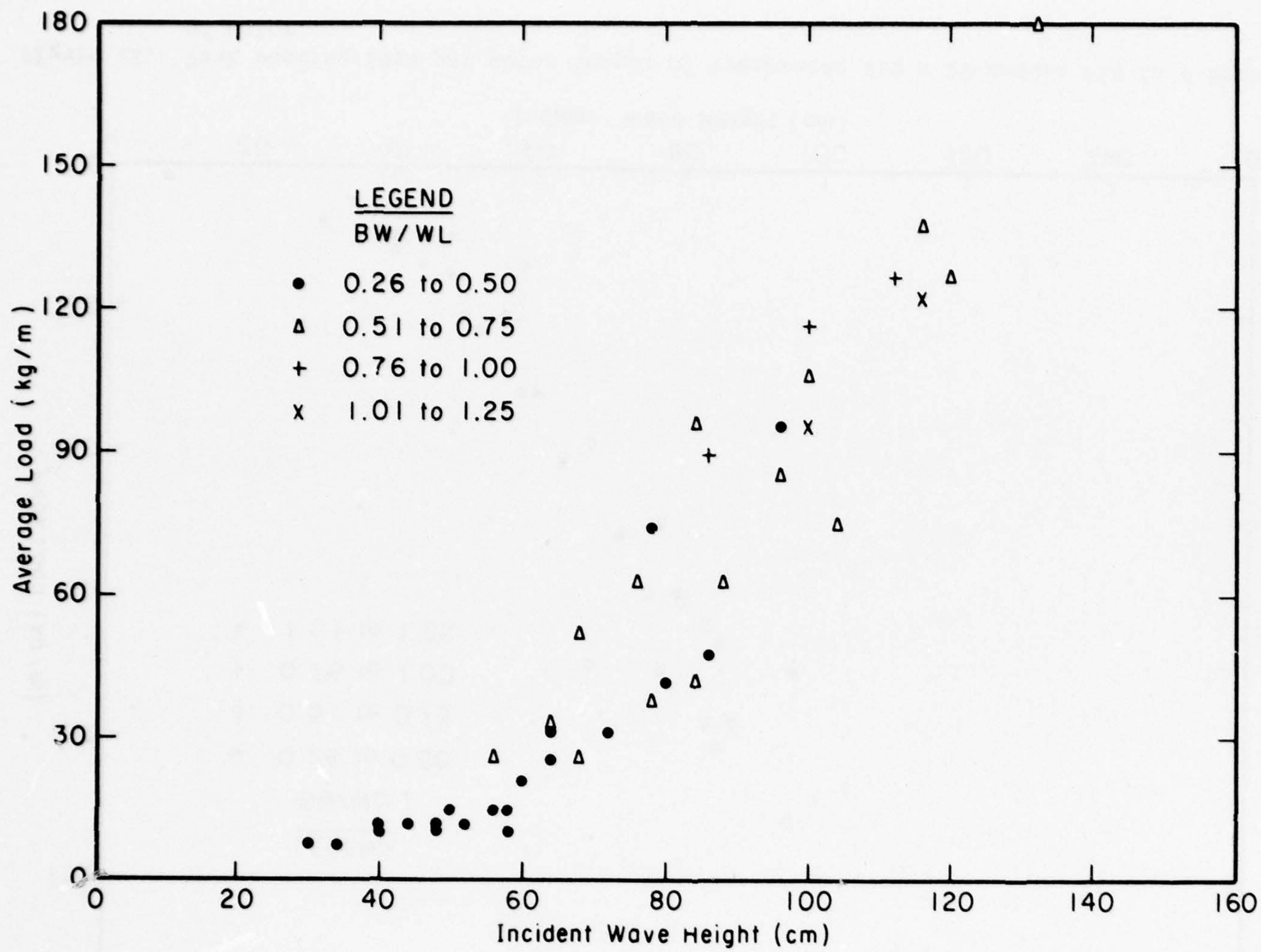


Figure 22. Average mooring load per meter length of breakwater for a 12-module FTB in 4 meters of water.

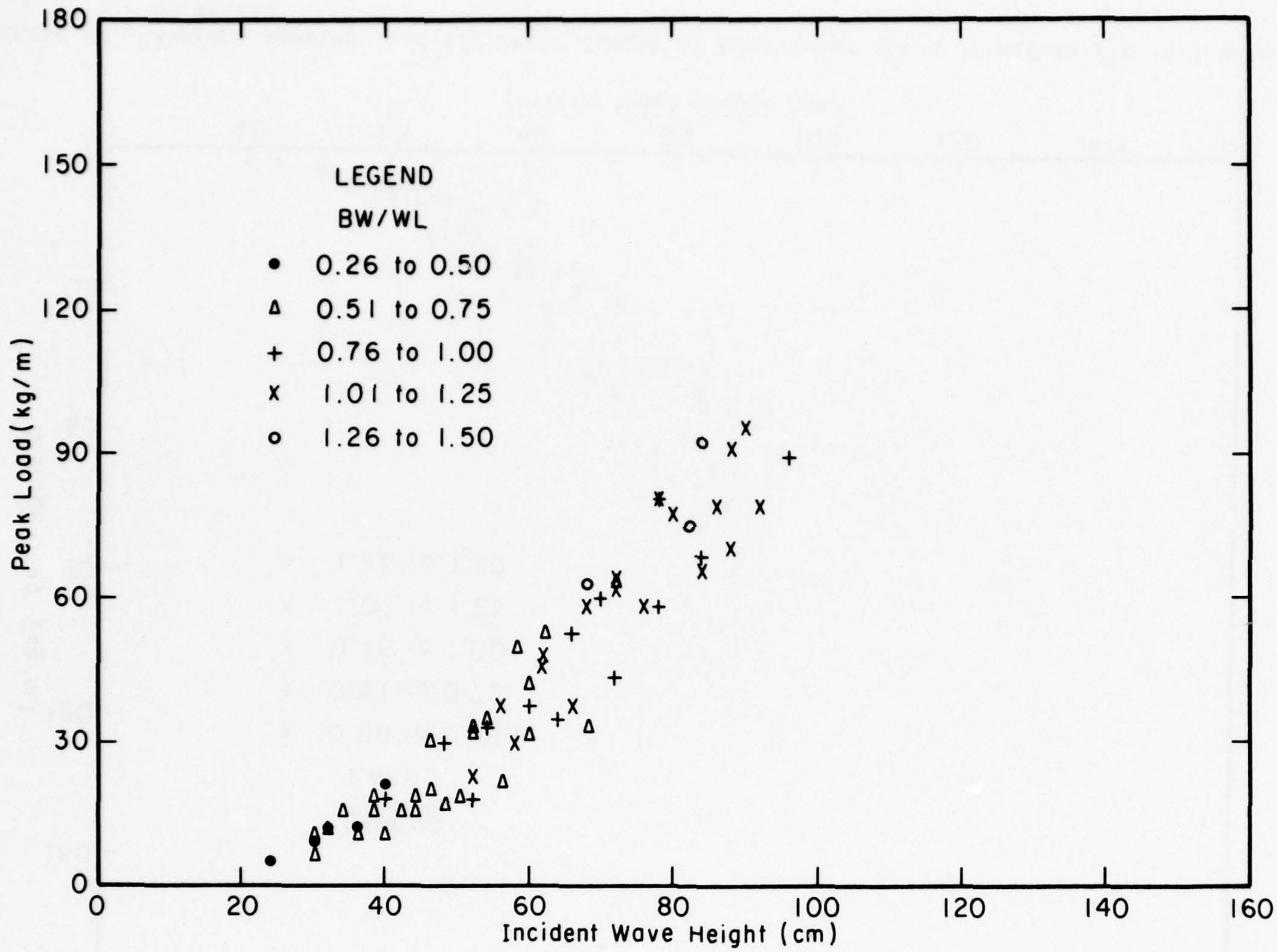


Figure 23. Peak mooring load per meter length of breakwater for a 12-module FTB in 2 meters of water.

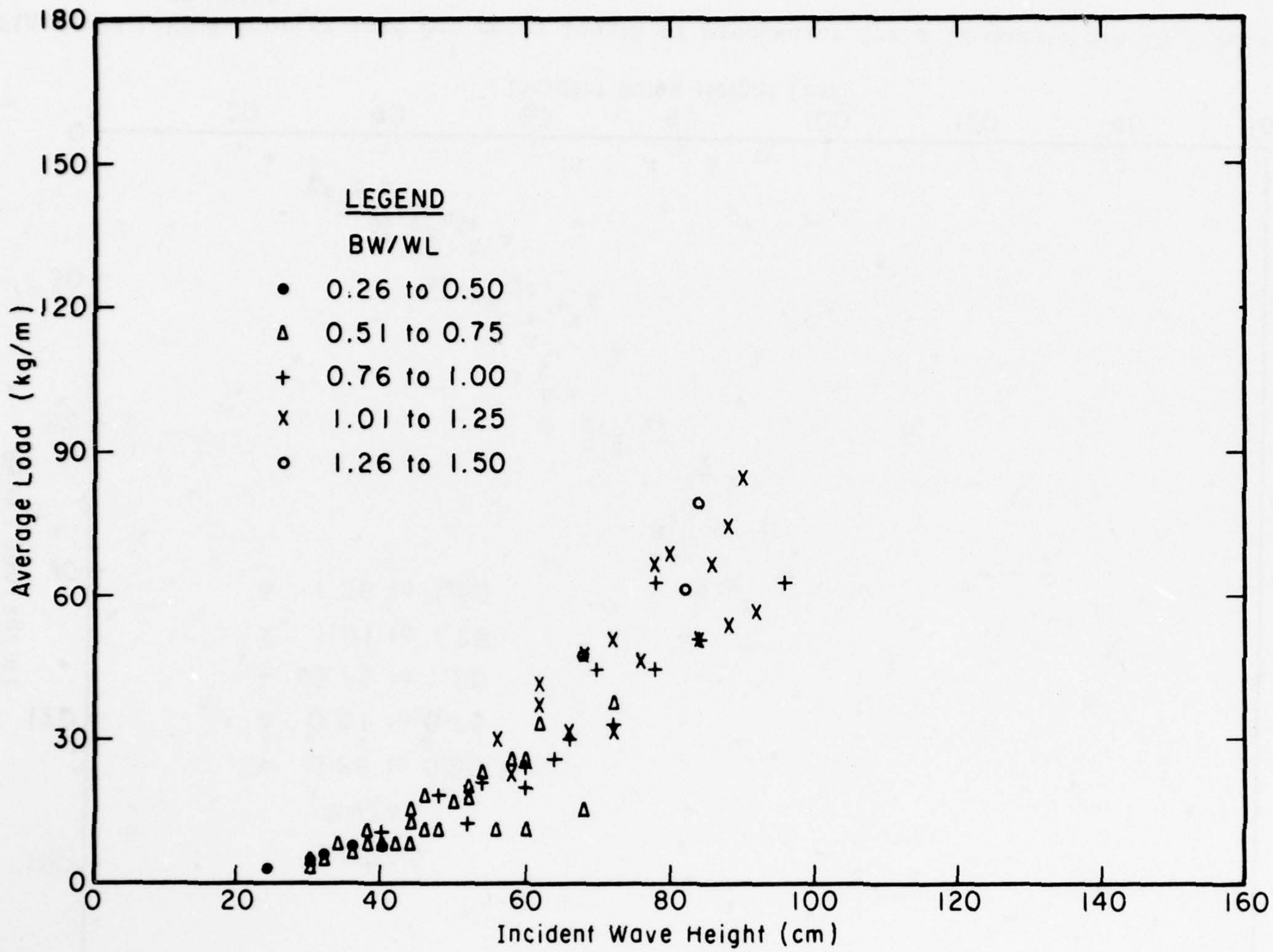


Figure 24. Average mooring load per meter length of breakwater for a 12-module FTB in 2 meters of water.

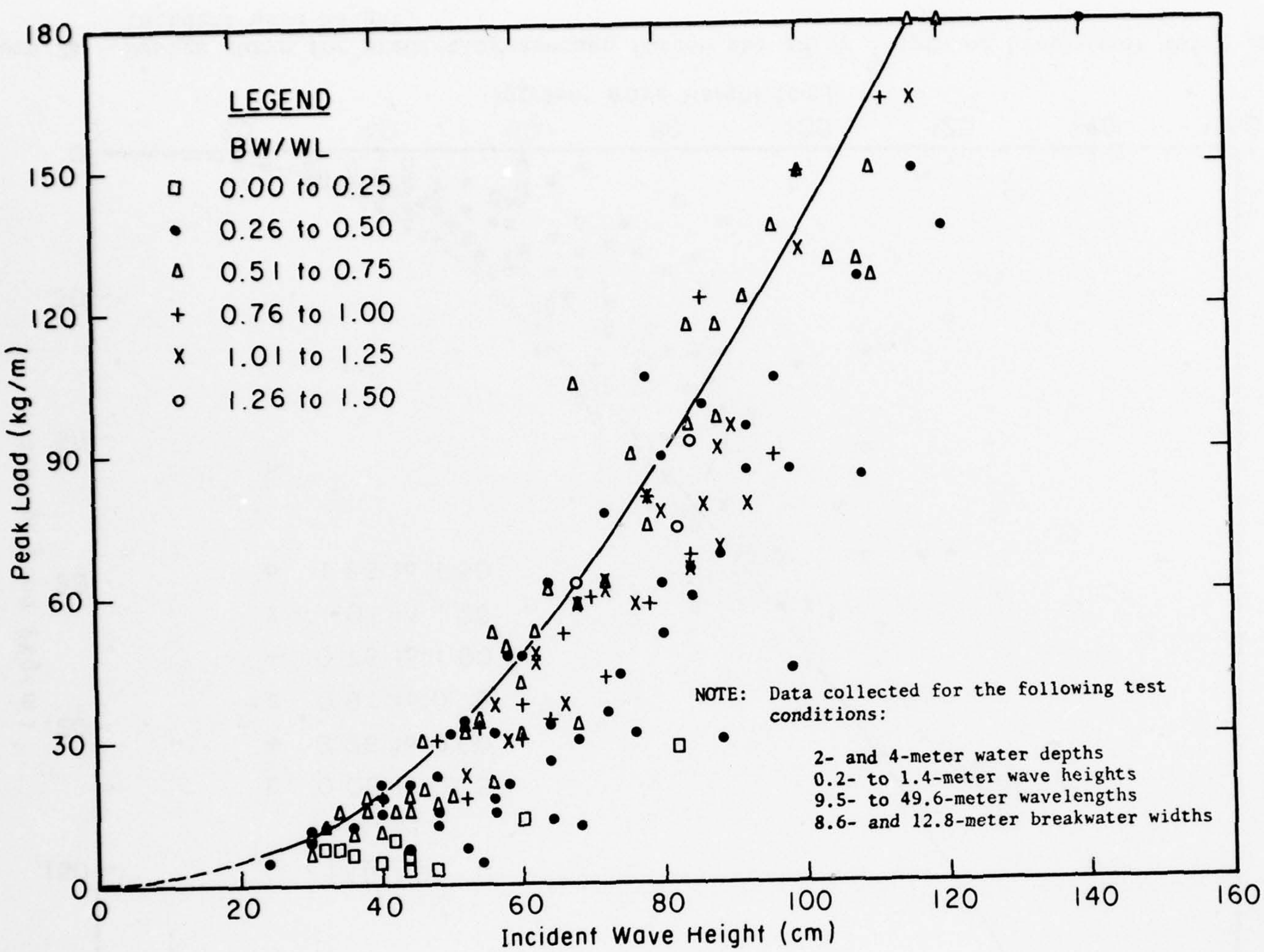


Figure 25. Design curve for predicting peak forces per meter length of breakwater for a given incident wave height.

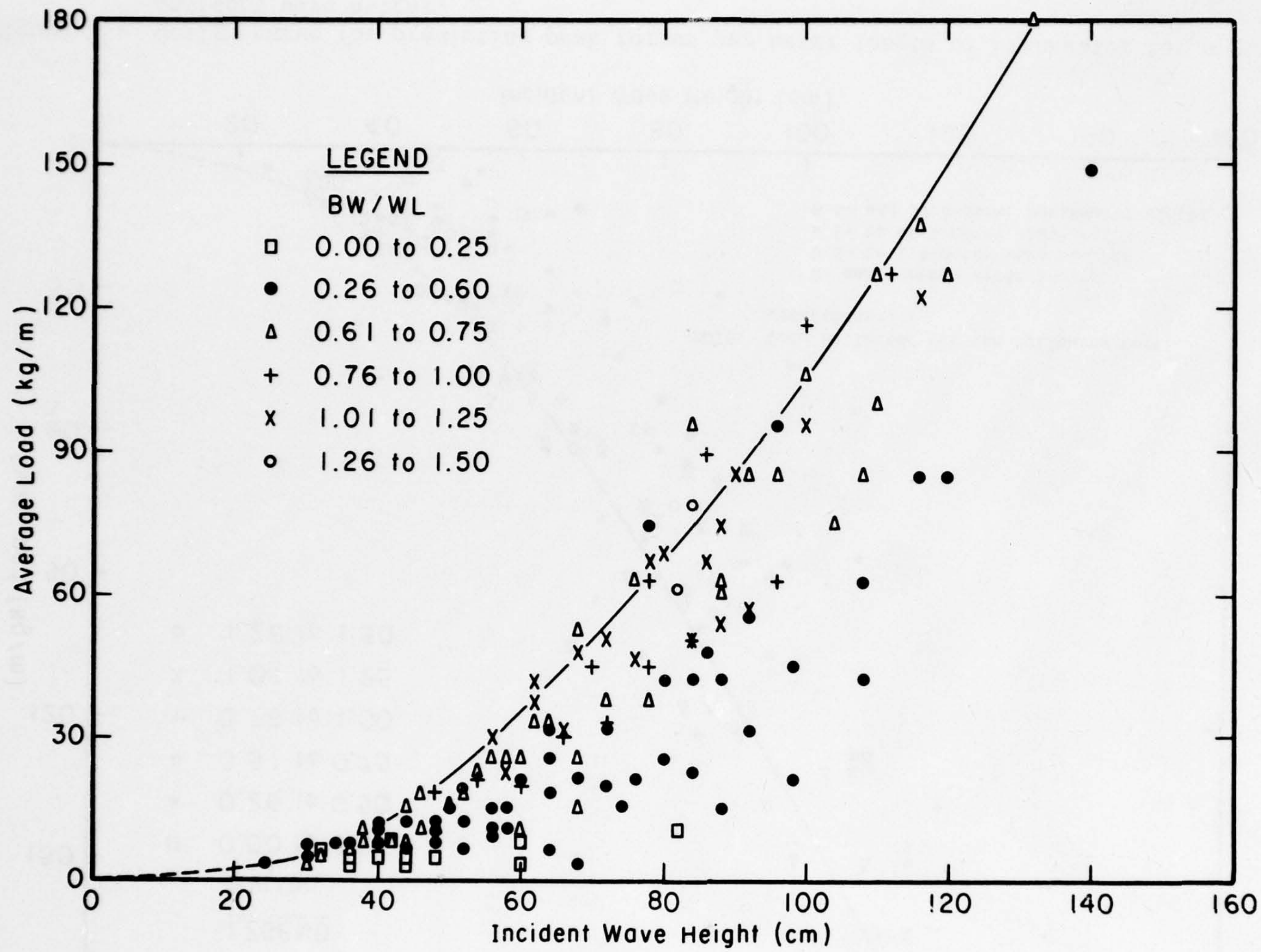


Figure 26. Design curve for predicting average forces per meter length of breakwater for a given incident wave height.

V. SUMMARY AND CONCLUSIONS

Prototype scale tests to determine the mooring load and wave transmission characteristics of a floating tire breakwater system using 8- and 12-Goodyear-tire modules were conducted in CERC's large wave tank using wave conditions similar to those found on semisheltered bodies of water. Two structure widths (4 and 6 modules, respectively) were tested in water depths of 2 and 4 meters.

Results of the tests showed that as the breakwater width to incident wavelength ratio, W/L, increases, the transmission coefficient, K_t, decreases. Also, for the same value of W/L, as the incident wave height, H_i, increases, the transmission coefficient decreases slightly. In addition the breakwater depth to water depth ratio does not appear to influence the transmission coefficient for the range of wave conditions and water depths tested. A suggested design curve for predicting the transmission coefficient for a given breakwater width to wavelength ratio is given (Fig. 18). The curve is valid for W/L ratios up to 1.4 and wave heights up to 140 centimeters.

The tests also showed that the peak and average mooring loads are primarily a function of the incident wave height and to a lesser extent the W/L ratio. In all cases, the larger the wave height and W/L ratio, the higher the force obtained. It was concluded that a conservative prediction for design of the mooring lines and anchor system for an FTB would be to use the mooring force load based on the peakload curve shown in Figure 25.

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APPENDIX

TEST RESULTS

The incident wave heights, transmitted wave heights, and peak and average loads measured during all tests are presented in Tables A-1, A-2, and A-3. Wave height measurements are to the nearest even centimeter and the loads are in total pounds recorded at the load cell.

Since several test conditions were repeated to assure quality control during the experiment, a composite incident wave height, transmitted wave height, and peak and average loads were determined for each stroke and wave period setting (Tables A-4, A-5, and A-6). The transmission coefficient, K_t, was obtained by dividing the transmitted wave height, H_t, by the incident height, H_i. The wavelength, L, was calculated using linear wave theory and the wave steepness, H_i/L was found by dividing the incident height by the wavelength. W/L represents the ratio of the the breakwater width to the wavelength. Peak force, F_p, and average force, F_n, are given in kilograms per meter of breakwater length parallel to the wave crest and uncorrected for the slope of the mooring line.

Table A-1. Wave measurements and mooring line force measurements for an eight-module floating tire breakwater in 4 meters of water.

Test No.	Stroke (m)	Wave period, T (s)	Incident height, H_i (cm)	Transmitted height, H_t (cm)	Total front load Peak (lb)	Total front load Avg (lb)
1	0.61	2.8	90	68	1,170	800
2	0.61	3.0	88	70	900	500
3	0.61	3.5	78	64	600	380
4	0.61	4.0	64	64	300	180
5	0.61	4.5	56	52	175	100
6	0.61	5.0	48	48	120	76
7	0.61	5.5	44	44	72	60
8	0.61	6.0	38	38	——	60
9	0.61	8.0	32	32	70	58
10	0.61	4.0	64	64	320	170
11	0.61	4.0	64	64	325	175
12	0.61	4.5	56	54	190	110
13	0.61	4.5	56	52	180	120
14	0.61	3.5	80	68	600	400
15	0.61	3.5	80	66	600	400
16	0.61	3.0	88	68	920	560
17	0.61	2.8	92	70	1,150	750
18	0.76	3.0	110	88	1,200	950
19	0.76	3.5	98	80	825	425
20	0.76	4.0	80	76	500	225
21	0.76	4.5	72	68	345	190
22	0.76	5.0	64	60	130	60
23	0.76	5.5	54	54	45	20
24	0.76	6.0	48	48	30	20
25	0.76	8.0	38	36	——	——
26	0.76	4.0	80	80	300	240
27	0.76	3.5	100	80	700	525
28	0.76	3.0	110	90	975	690
29	0.91	3.5	116	96	900	600
30	0.91	4.0	92	92	875	490
31	0.91	4.5	84	80	625	400
32	0.91	5.0	76	72	300	200
33	0.91	5.5	68	64	120	40
34	0.91	6.0	60	60	130	40
35	0.91	8.0	44	42	——	——
36	0.91	4.5	84	80	——	400
37	0.91	4.0	92	92	900	525
38	0.91	4.0	92	92	950	525
39	0.91	3.5	116	98	——	——
40	0.91	8.0	44	42	[illegible]	38
41	0.91	4.5	84	80	520	300
42	0.91	4.0	94	94	800	400
43	0.91	3.5	116	98	1,400	800
44	0.91	4.5	84	80	450	200
45	0.91	3.75	108	96	1,200	600
46	0.91	4.25	88	84	650	400
47	0.91	7.75	48	48	——	50
48	0.91	8.25	42	40	92	80
49	0.68	2.8	110	80	1,400	1,200
50	0.68	3.0	108	80	1,225	800
51	0.68	3.5	92	72	825	240
52	0.68	4.0	76	72	440	120
53	0.68	4.5	66	60	220	100
54	0.68	4.0	72	70	200	120
55	0.68	4.0	74	72	410	120
56	0.68	3.75	84	72	500	220
57	0.68	4.25	68	64	260	200
58	0.68	3.5	92	72	720	300
59	0.68	3.75	84	72	560	220
60	0.68	4.0	74	68	410	150
61	0.68	4.25	68	64	280	200
62	0.68	4.5	64	60	250	180
63	0.68	5.0	56	54	150	90
64	0.68	5.5	52	52	80	60
65	0.68	6.0	44	44	——	60
66	0.68	8.0	36	32	56	40
67	0.68	6.0	44	44	72	60
68	0.68	7.75	36	36	60	45
69	0.68	8.25	34	32	70	60
70	0.68	7.0	40	40	55	45
71	1.06	3.5	140	116	1,700	1,400
72	1.06	4.0	120	110	1,300	800
73	1.06	4.5	108	94	800	400
74	1.06	5.0	98	88	420	200
75	1.06	5.5	88	76	280	150
76	1.06	6.0	82	68	270	100
77	1.06	8.0	60	52	130	80

Table A-2. Wave measurements and mooring line force measurements for a 12-module floating tire breakwater in 4 meters of water.

Test No.	Stroke	Wave period, T	Incident height, H_i	Transmitted height, H_t	Total front load	
	(m)	(s)	(cm)	(cm)	Peak (lb)	Avg (lb)
201	0.61	2.8	100	60	1,200	850
202	0.61	2.8	104	60	1,200	900
203	0.61	3.0	86	62	1,150	850
204	0.61	3.0	86	62	1,000	850
205	0.61	3.5	76	64	850	600
206	0.61	4.0	68	60	550	240
207	0.61	4.5	54	52	500	250
208	0.61	5.0	50	48	300	150
209	0.61	5.5	44	42	200	120
210	0.61	6.0	40	40	180	120
211	0.61	8.0	30	28	125	80
212	0.61	2.8	96	58	1,250	1,000
213	0.61	3.0	88	64	1,160	950
214	0.61	3.5	76	64	850	600
215	0.61	4.0	68	60	500	210
216	0.61	4.5	56	52	475	275
217	0.61	5.0	52	50	290	180
218	0.61	4.0	68	60	--------	200
219A	0.68	2.8	116	64	1,550	1,100
220A	0.68	3.0	100	76	1,400	1,050
221A	0.68	3.5	88	72	1,000	600
222A	0.68	4.0	76	70	720	350
223A	0.68	4.5	60	60	580	320
224A	0.68	5.0	56	56	460	--------
219	0.68	2.8	116	60	1,460	1,200
220	0.68	3.0	100	72	1,375	1,100
221	0.68	3.0	100	74	1,400	1,150
222	0.68	3.5	88	74	1,150	700
223	0.68	4.0	78	68	700	300
224	0.68	2.8	116	66	--------	1,150
225	0.68	3.0	100	72	1,300	1,100
226	0.68	3.5	88	76	1,100	600
227	0.68	4.0	78	68	650	350
228	0.68	4.5	64	60	575	400
229	0.68	5.0	60	56	400	200
230	0.68	5.5	52	48	200	125
231	0.68	5.5	52	48	325	100
232	0.68	6.0	48	46	220	125
233	0.68	8.0	34	34	80	70
234	0.76	3.0	112	80	1,550	1,200
235	0.76	3.5	96	80	1,300	800
236	0.76	4.0	84	76	900	400
237	0.76	4.5	68	68	--------	--------
238	0.76	4.5	68	68	980	500
239	0.76	5.0	64	64	600	300
240	0.76	5.5	58	56	400	150
241	0.76	5.5	58	56	450	150
242	0.76	6.0	56	54	300	150
243	0.76	8.0	40	40	150	100
244	0.91	3.5	120	92	1,700	1,200
245	0.91	4.0	104	92	1,220	700
246	0.91	4.5	84	84	1,100	900
247	0.91	5.0	78	76	1,000	700
248	0.91	5.5	72	66	740	300
249	0.91	6.0	64	64	600	250
250	0.91	8.0	48	48	150	100
251	1.06	8.0	58	56	200	100
252	1.06	6.0	80	72	850	400
253	1.06	5.5	86	76	950	450
254	1.06	5.0	96	92	1,000	900
255	1.06	4.5	100	100	1,400	1,000
256	1.06	4.0	116	104	1,700	1,300
257	1.06	3.5	132	108	--------	1,700

Table A-3. Wave measurements and mooring line force measurements for a 12-module floating tire breakwater in 2 meters of water.

Test No.	Stroke (m)	Wave period, T (s)	Incident height, H_i (cm)	Transmitted height, H_t (cm)	Total front load Peak (lb)	Total front load Avg (lb)
301	1.06	8.0	38	38	60	40
302	1.06	6.0	50	42	260	150
303	1.06	5.5	60	44	400	250
304	1.06	5.0	66	56	320	150
305	1.06	4.5	72	56	600	350
306	1.06	4.0	78	58	700	600
307	1.06	3.5	96	58	700	600
308	1.06	3.0	72	44	600	300
309	1.06	3.2	92	52	750	500
310	0.61	2.64	68	24	600	460
311	0.61	2.8	62	30	440	400
312	0.61	3.0	56	32	360	280
313	0.61	3.2	52	32	220	150
314	0.61	3.5	52	32	180	100
315	0.61	4.0	40	32	170	110
316	0.61	4.5	36	30	110	60
317	0.61	5.0	34	28	70	50
318	0.61	5.5	30	24	60	40
319	0.61	6.0	26	22	------	------
320	0.61	8.0	20	20	------	------
321	0.61	3.5	52	32	180	120
322	0.61	3.2	52	32	190	170
323	0.61	3.0	54	32	320	250
324	0.61	2.8	62	28	480	360
325	0.61	2.64	66	22	600	460
326	0.61	2.8	62	28	460	400
327	0.68	2.64	82	24	700	580
328	0.68	2.64	82	24	660	560
329	0.68	2.8	74	32	580	480
330	0.68	3.0	62	38	440	340
331	0.68	3.2	58	34	280	200
332	0.68	3.5	60	36	250	160
333	0.68	4.0	48	36	280	170
334	0.68	4.5	42	32	140	70
335	0.68	5.0	40	32	110	70
336	0.68	5.5	34	28	140	80
337	0.68	6.0	30	26	100	50
338	0.68	8.0	22	22	------	------
339	0.68	3.5	60	36	250	190
340	0.68	3.2	58	36	280	220
341	0.68	3.2	56	34	280	220
342	0.68	3.0	62	36	450	350
343	0.68	2.8	72	32	620	500
344	0.68	2.64	84	26	760	600
345	0.76	2.64	84	28	850	740
346	0.76	2.8	80	34	740	650
347	0.76	3.0	66	38	550	430
348	0.76	3.2	64	38	350	280
349	0.76	3.5	64	40	325	200
350	0.76	4.0	52	40	350	200
351	0.76	4.5	44	38	190	110
352	0.76	2.64	84	30	870	750
353	0.76	5.0	44	36	140	80
354	0.76	5.5	38	32	170	70
355	0.76	6.0	32	30	120	50
356	0.76	8.0	24	24	55	40
357	0.76	2.8	80	34	720	640
358	0.76	3.0	68	38	540	460
359	0.76	3.2	66	40	355	300
360	0.76	3.5	58	42	335	240
36.	0.76	4.0	54	44	310	200
362	0.76	4.5	46	40	190	100
363	0.76	5.0	44	38	120	65
364	0.83	8.0	30	30	90	50
365	0.83	6.0	40	32	140	100
366	0.83	5.5	44	36	180	140
367	0.83	5.0	48	42	160	80
368	0.83	4.5	52	40	270	160
369	0.83	4.0	60	46	330	225
370	0.83	3.5	72	42	400	300
371	0.83	3.2	74	44	470	410
372	0.83	3.0	76	44	720	640
373	0.83	2.8	90	40	900	800

Table A-3. Wave measurements and mooring line force measurements for a 12-module floating tire breakwater in 2 meters of water. —Continued

Test No.	Stroke (m)	Wave period, T (s)	Incident height, H_i (cm)	Transmitted height, H_t (cm)	Total front load: Peak (lb)	Total front load: Avg (lb)
374	0.83	8.0	28	28	55	40
375	0.83	6.0	38	34	145	105
376	0.83	5.5	46	34	285	150
377	0.83	5.0	50	44	165	100
378	0.83	4.5	52	44	310	175
379	0.83	4.0	60	46	350	210
380	0.83	3.5	72	46	410	320
381	0.83	3.0	80	44	760	600
382	0.83	3.2	76	40	550	440
383	0.83	2.8	92	40	980	740
384	0.91	8.0	32	32	85	40
385	0.91	6.0	44	36	175	120
386	0.91	5.5	50	38	180	155
387	0.91	5.0	56	46	165	110
388	0.91	4.5	58	46	350	240
389	0.91	4.0	68	50	450	280
390	0.91	3.5	80	50	525	425
391	0.91	3.2	84	44	590	480
392	0.91	4.5	58	46	425	245
393	0.91	4.0	68	52	525	340
394	0.91	5.0	56	46	190	105
395	0.91	3.0	88	44	800	640
396	0.91	8.0	32	32	140	60
397	0.91	6.0	42	36	220	155
398	0.91	5.5	50	36	210	155
399	0.91	5.0	54	44	205	100
400	0.91	4.5	58	46	475	250
401	0.91	4.0	64	52	510	260
402	0.91	3.5	76	50	515	420
403	0.91	3.2	82	42	620	445
404	0.91	3.0	84	44	860	710
405	0.91	3.5	78	48	550	420
406	0.91	8.0	32	32	120	60
407	0.91	4.0	64	52	500	290
408	0.98	8.0	36	36	120	55
409	0.98	6.0	48	40	280	170
410	0.98	5.5	54	40	330	210
411	0.98	5.0	60	50	265	90
412	0.98	4.5	64	50	-----	310
413	0.98	4.5	62	48	460	280
414	0.98	4.0	70	56	560	420
415	0.98	3.5	84	52	660	500
416	0.98	3.2	88	46	650	480
417	0.98	3.0	86	52	750	630
418	0.98	8.0	36	36	110	70
419	0.98	6.0	46	40	285	170
420	0.98	5.5	54	40	290	220
421	0.98	5.0	64	48	300	100
422	0.98	4.0	70	56	675	380
423	0.98	3.5	84	52	650	480
424	0.98	3.2	88	48	660	510
424	0.98	4.5	62	50	490	345
426	0.98	8.0	34	34	135	55
427	1.06	8.0	40	38	155	60
428	1.06	6.0	54	44	300	190
429	1.06	5.5	60	42	300	240
430	1.06	5.0	68	56	270	140
431	1.06	4.5	70	52	805	460
432	1.06	4.0	78	60	760	580
433	1.06	3.5	96	56	840	600
434	1.06	3.2	92	48	910	540
435	1.06	8.0	40	36	200	80
436	1.06	6.0	52	44	330	210
437	1.22	8.0	48	46	-----	-----
438	1.22	6.0	64	48	-----	-----
439	1.22	5.5	70	52	-----	-----
440	1.22	5.0	76	64	-----	-----
441	1.22	4.5	80	62	-----	-----
442	1.22	4.0	88	68	-----	-----
443	1.22	3.5	100	60	-----	-----
444	1.22	8.0	46	44	-----	-----
445	1.22	6.0	60	48	-----	-----
446	1.22	6.0	60	48	-----	-----

Table A-4. Summary data table for an eight-module floating tire breakwater in 4 meters of water.[1]

Stroke (m)	T (s)	H_i (cm)	H_t (cm)	K_t	L (m)	H_i/L	W/L	F_p (kg/m)	F_n (kg/m)
0.61	2.80	92	70	0.761	11.9	0.0774	0.72	122.0	84.8
0.61	3.00	88	68	0.773	13.4	0.0656	0.64	96.7	59.5
0.61	3.50	80	66	0.825	17.2	0.0466	0.50	62.5	41.7
0.61	4.00	64	64	1.000	20.9	0.0307	0.41	32.7	17.9
0.61	4.50	56	52	0.929	24.4	0.0229	0.35	17.9	10.4
0.61	5.00	48	48	1.000	27.9	0.0172	0.31	11.9	7.4
0.61	5.50	44	44	1.000	31.4	0.0140	0.27	7.4	6.0
0.61	6.00	38	38	1.000	34.8	0.0109	0.25	0.0	6.0
0.61	8.00	32	32	1.000	48.0	0.0067	0.18	7.4	6.0
0.68	2.80	110	80	0.727	11.9	0.0925	0.72	148.8	126.5
0.68	3.00	108	80	0.741	13.4	0.0806	0.64	129.5	84.8
0.68	3.50	92	72	0.783	17.2	0.0536	0.50	86.3	31.2
0.68	3.75	84	72	0.857	19.0	0.0441	0.45	59.5	22.3
0.68	4.00	74	72	0.973	20.9	0.0355	0.41	43.2	14.9
0.68	4.25	68	64	0.941	22.7	0.0300	0.38	29.8	20.8
0.68	4.50	64	60	0.938	24.4	0.0262	0.35	25.3	17.9
0.68	5.00	56	54	0.964	27.9	0.0200	0.31	14.9	8.9
0.68	5.50	52	52	1.000	31.4	0.0166	0.27	7.4	6.0
0.68	6.00	44	44	1.000	34.8	0.0127	0.25	6.0	4.5
0.68	7.00	40	40	1.000	41.4	0.0097	0.21	4.5	4.5
0.68	7.75	36	36	1.000	46.4	0.0078	0.18	6.0	4.5
0.68	8.00	36	32	0.889	48.0	0.0075	0.18	6.0	3.0
0.68	8.25	34	32	0.941	49.6	0.0068	0.17	7.4	6.0
0.76	3.00	110	88	0.800	13.4	0.0821	0.64	126.5	99.7
0.76	3.50	98	80	0.816	17.2	0.0570	0.50	86.3	44.6
0.76	4.00	80	76	0.950	20.9	0.0383	0.41	52.1	25.3
0.76	4.50	72	68	0.944	24.4	0.0295	0.35	35.7	19.3
0.76	5.00	64	60	0.938	27.9	0.0229	0.31	13.4	6.0
0.76	5.50	54	54	1.000	31.4	0.0172	0.27	4.5	1.5
0.76	6.00	48	48	1.000	34.8	0.0138	0.25	3.0	1.5
0.76	8.00	38	36	0.947	48.0	0.0079	0.18	0.0	0.0
0.91	3.50	116	98	0.845	17.2	0.0675	0.50	148.8	84.8
0.91	3.75	108	96	0.889	19.0	0.0567	0.45	126.5	62.5
0.91	4.00	92	92	1.000	20.9	0.0441	0.41	95.2	55.1
0.91	4.25	88	84	0.955	22.7	0.0388	0.38	68.4	41.7
0.91	4.50	84	80	0.952	24.4	0.0344	0.35	65.5	41.7
0.91	5.00	76	72	0.947	27.9	0.0272	0.31	31.2	20.8
0.91	5.50	68	64	0.941	31.4	0.0217	0.27	11.9	3.0
0.91	6.00	60	60	1.000	34.8	0.0173	0.25	13.4	3.0
0.91	7.75	48	48	1.000	46.4	0.0104	0.18	0.0	4.5
0.91	8.00	44	42	0.955	48.0	0.0092	0.18	3.0	3.0
0.91	8.25	42	40	0.952	49.6	0.0085	0.17	8.9	7.4
1.06	3.50	140	116	0.829	17.2	0.0815	0.50	180.0	148.8
1.06	4.00	120	110	0.917	20.9	0.0575	0.41	136.9	84.8
1.06	4.50	108	94	0.870	24.4	0.0442	0.35	84.8	41.7
1.06	5.00	98	88	0.898	27.9	0.0351	0.31	44.6	20.8
1.06	5.50	88	76	0.864	31.4	0.0280	0.27	29.8	14.9
1.06	6.00	82	68	0.829	34.8	0.0236	0.25	28.3	10.4
1.06	8.00	60	52	0.867	48.0	0.0125	0.18	13.4	7.4

[1] Breakwater width = 8.5 meters; water depth = 400 centimeters; Y/D = 0.15; front mooring line slope = 1 on 7.

Table A-5. Summary data table for a 12-module floating tire breakwater in 4 meters of water.[1]

Stroke (m)	T (s)	H_i (cm)	H_t (cm)	K_t	L (m)	H_i/L	W/L	F_p (kg/m)	F_n (kg/m)
0.61	2.80	100	60	0.600	11.9	0.0841	1.08	132.4	95.2
0.61	3.00	86	62	0.721	13.4	0.0642	0.95	122.0	89.3
0.61	3.50	76	64	0.842	17.2	0.0442	0.75	89.3	62.5
0.61	4.00	68	60	0.882	20.9	0.0326	0.61	58.0	25.3
0.61	4.50	56	52	0.929	24.4	0.0229	0.52	52.1	25.3
0.61	5.00	50	48	0.960	27.9	0.0179	0.46	31.2	14.9
0.61	5.50	44	42	0.955	31.4	0.0140	0.41	20.8	11.9
0.61	6.00	40	40	1.000	34.8	0.0115	0.37	17.9	11.9
0.61	8.00	30	28	0.933	48.0	0.0062	0.27	11.9	7.4
0.68	2.80	116	64	0.552	11.9	0.0976	1.08	163.7	122.0
0.68	3.00	100	74	0.740	13.4	0.0746	0.95	148.8	116.1
0.68	3.50	88	74	0.841	17.2	0.0512	0.75	116.1	62.5
0.68	4.00	78	68	0.872	20.9	0.0374	0.61	74.4	37.2
0.68	4.50	64	60	0.938	24.4	0.0262	0.52	61.0	32.7
0.68	5.00	60	56	0.933	27.9	0.0215	0.46	47.6	20.8
0.68	5.50	52	48	0.923	31.4	0.0166	0.41	34.2	11.9
0.68	6.00	48	46	0.958	34.8	0.0138	0.37	22.3	11.9
0.68	8.00	34	34	1.000	48.0	0.0071	0.27	7.4	7.4
0.76	3.00	112	80	0.714	13.4	0.0835	0.95	163.7	126.5
0.76	3.50	96	80	0.833	17.2	0.0559	0.75	136.9	84.8
0.76	4.00	84	76	0.905	20.9	0.0403	0.61	95.2	41.7
0.76	4.50	68	68	1.000	24.4	0.0278	0.52	104.2	52.1
0.76	5.00	64	64	1.000	27.9	0.0229	0.46	62.5	31.2
0.76	5.50	58	56	0.966	31.4	0.0185	0.41	47.6	14.9
0.76	6.00	56	54	0.964	34.8	0.0161	0.37	31.2	14.9
0.76	8.00	40	40	1.000	48.0	0.0083	0.27	14.9	10.4
0.91	3.50	120	92	0.767	17.2	0.0699	0.75	180.0	126.5
0.91	4.00	104	92	0.885	20.9	0.0499	0.61	129.5	74.4
0.91	4.50	84	84	1.000	24.4	0.0344	0.52	116.1	95.2
0.91	5.00	78	76	0.974	27.9	0.0279	0.46	105.6	74.4
0.91	5.50	72	66	0.917	31.4	0.0229	0.41	77.4	31.2
0.91	6.00	64	64	1.000	34.8	0.0184	0.37	62.5	25.3
0.91	8.00	48	48	1.000	48.0	0.0100	0.27	14.9	10.4
1.06	3.50	132	108	0.818	17.2	0.0768	0.75	0.0	180.0
1.06	4.00	116	104	0.897	20.9	0.0556	0.61	180.0	136.9
1.06	4.50	100	100	1.000	24.4	0.0409	0.52	148.8	105.6
1.06	5.00	96	92	0.958	27.9	0.0344	0.46	105.6	95.2
1.06	5.50	86	76	0.884	31.4	0.0274	0.41	99.7	47.6
1.06	6.00	80	72	0.900	34.8	0.0230	0.37	89.3	41.7
1.06	8.00	58	56	0.966	48.0	0.0121	0.27	20.8	10.4

[1] Breakwater width = 12.8 meters; water depth = 400 centimeters; Y/D = 0.15; front mooring line slope = 1 on 7.

Table A-6. Summary data table for a 12-module floating tire breakwater in 2 meters of water.[1]

Stroke (m)	T (s)	H_i (cm)	H_t (cm)	K_t	L (m)	H_i/L	W/L	F_p (kg/m)	F_n (kg/m)
0.61	2.64	68	24	0.353	9.5	0.0719	1.35	62.5	47.6
0.61	2.80	62	28	0.452	10.3	0.0603	1.24	47.6	41.7
0.61	3.00	56	32	0.571	11.3	0.0495	1.13	37.2	29.8
0.61	3.20	52	32	0.615	12.3	0.0422	1.04	22.3	17.9
0.61	3.50	52	32	0.615	13.8	0.0377	0.93	17.9	11.9
0.61	4.00	40	32	0.800	16.2	0.0247	0.79	17.9	10.4
0.61	4.50	36	30	0.833	18.6	0.0193	0.69	10.4	6.0
0.61	5.50	30	24	0.800	23.3	0.0129	0.55	6.0	3.0
0.61	6.00	26	22	0.846	25.6	0.0102	0.50	0.0	0.0
0.61	8.00	20	20	1.000	34.7	0.0058	0.37	0.0	0.0
0.68	2.64	82	26	0.317	9.5	0.0867	1.35	74.4	61.0
0.68	2.80	72	32	0.444	10.3	0.0700	1.24	61.0	50.6
0.68	3.00	62	36	0.581	11.3	0.0548	1.13	46.1	37.2
0.68	3.20	58	34	0.586	12.3	0.0471	1.04	29.8	22.3
0.68	3.50	60	36	0.600	13.8	0.0435	0.93	29.8	19.3
0.68	4.00	48	36	0.750	16.2	0.0296	0.79	29.8	17.9
0.68	4.50	42	32	0.762	18.6	0.0226	0.69	14.9	7.4
0.68	5.00	40	32	0.800	21.0	0.0191	0.61	10.4	7.4
0.68	5.50	34	28	0.824	23.3	0.0146	0.55	14.9	7.4
0.68	6.00	30	26	0.867	25.6	0.0117	0.50	10.4	4.5
0.68	8.00	22	22	1.000	34.7	0.0063	0.37	0.0	0.0
0.76	2.64	84	30	0.357	9.5	0.0888	1.35	92.3	78.9
0.76	2.80	80	34	0.425	10.3	0.0778	1.24	77.4	68.4
0.76	3.00	68	38	0.559	11.3	0.0601	1.13	58.0	47.6
0.76	3.20	66	40	0.606	12.3	0.0536	1.04	37.2	31.2
0.76	3.50	64	42	0.656	13.8	0.0464	0.93	34.2	25.3
0.76	4.00	54	44	0.815	16.2	0.0333	0.79	32.7	20.8
0.76	4.50	46	40	0.870	18.6	0.0247	0.69	19.3	10.4
0.76	5.00	44	38	0.864	21.0	0.0210	0.61	14.9	7.4
0.76	5.50	38	32	0.842	23.3	0.0163	0.55	17.9	7.4
0.76	6.00	32	30	0.938	25.6	0.0125	0.50	11.9	4.5
0.76	8.00	24	24	1.000	34.7	0.0069	0.37	4.5	3.0
0.83	2.80	90	40	0.444	10.3	0.0875	1.24	95.2	84.8
0.83	3.00	78	44	0.564	11.3	0.0690	1.13	80.4	67.0
0.83	3.20	76	40	0.526	12.3	0.0617	1.04	58.0	46.1
0.83	3.50	72	44	0.611	13.8	0.0522	0.93	43.2	32.7
0.83	4.00	60	46	0.767	16.2	0.0370	0.79	37.2	23.8
0.83	4.50	52	40	0.769	18.6	0.0279	0.69	32.7	17.9
0.83	5.00	48	42	0.875	21.0	0.0229	0.61	16.4	10.4
0.83	5.50	44	36	0.818	23.3	0.0189	0.55	17.9	14.9
0.83	6.00	38	34	0.895	25.6	0.0149	0.50	14.9	10.4
0.83	8.00	30	30	1.000	34.7	0.0086	0.37	8.9	4.5
0.91	3.00	88	44	0.500	11.3	0.0778	1.13	90.8	74.4
0.91	3.20	84	44	0.524	12.3	0.0682	1.04	65.5	50.6
0.91	3.50	78	50	0.641	13.8	0.0565	0.93	58.0	44.6
0.91	4.00	66	52	0.788	16.2	0.0407	0.79	52.1	29.8
0.91	4.50	58	46	0.793	18.6	0.0312	0.69	49.1	25.3
0.91	5.00	56	46	0.821	21.0	0.0267	0.61	20.8	10.4
0.91	5.50	50	38	0.760	23.3	0.0215	0.55	17.9	16.4
0.91	6.00	44	36	0.818	25.6	0.0172	0.50	17.9	11.9
0.91	8.00	32	32	1.000	34.7	0.0092	0.37	11.9	6.0
0.98	3.00	86	52	0.605	11.3	0.0761	1.13	78.9	67.0
0.98	3.20	88	46	0.523	12.3	0.0715	1.04	69.9	53.6
0.98	3.50	84	52	0.619	13.8	0.0609	0.93	68.4	50.6
0.98	4.00	70	56	0.800	16.2	0.0431	0.79	59.5	44.6
0.98	4.50	62	50	0.806	18.6	0.0333	0.69	52.1	32.7
0.98	5.00	60	48	0.800	21.0	0.0286	0.61	31.2	10.4
0.98	5.50	54	40	0.741	23.3	0.0232	0.55	34.2	22.3
0.98	6.00	46	40	0.870	25.6	0.0180	0.50	29.8	17.9
0.98	8.00	36	36	1.000	34.7	0.0104	0.37	11.9	7.4
1.06	3.00	72	44	0.611	11.3	0.0637	1.13	62.5	31.2
1.06	3.20	92	52	0.565	12.3	0.0747	1.04	78.9	56.5
1.06	3.50	96	56	0.583	13.8	0.0696	0.93	89.3	62.5
1.06	4.00	78	60	0.769	16.2	0.0481	0.79	80.4	62.5
1.06	4.50	72	56	0.778	18.6	0.0387	0.69	62.5	37.2
1.06	5.00	68	56	0.824	21.0	0.0325	0.61	32.7	14.9
1.06	5.50	60	44	0.733	23.3	0.0258	0.55	41.7	25.3
1.06	6.00	52	44	0.846	25.6	0.0203	0.50	31.2	19.3
1.06	8.00	40	38	0.950	34.7	0.0115	0.37	20.8	7.4
1.22	3.50	100	60	0.600	13.8	0.0725	0.93	0.0	0.0
1.22	4.00	88	62	0.773	16.2	0.0542	0.79	0.0	0.0
1.22	4.50	80	62	0.775	18.6	0.0430	0.69	0.0	0.0
1.22	5.00	76	64	0.842	21.0	0.0363	0.61	0.0	0.0
1.22	5.50	70	52	0.743	23.3	0.0301	0.55	0.0	0.0
1.22	6.00	60	48	0.800	25.6	0.0235	0.50	0.0	0.0
1.22	8.00	48	46	0.958	34.7	0.0138	0.37	0.0	0.0

[1] Breakwater width = 12.8 meters; water depth = 200 centimeters; Y/D = 0.30; front mooring line slope = 1 on 10.

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